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# EVALUATION OF DCS III TRANSMISSION ALTERNATIVES PHASE 1A REPORT

26 MAY 1980

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Prepared for
Defense Communications Agency
Defense Communications Engineering Center
Reston, Virginia 22090

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| Millimeter Wave LOS System | Cable/Optical Fiber System |

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This report covers DCS III requirements, transmission me a characteristics, regulatory factors, and DCS III transmission system alte natives. Appendix A documents results of transmission-media investigations. Appendix B presents a detailed review of rules, procedures, regulations, standards, and recommendations established by national/international organizations. Appendix C provides a description of topographic and climatic conditions in Germany, Turkey, and Hawaii.

35142

# EVALUATION OF DCS III TRANSMISSION ALTERNATIVES PHASE 1A REPORT

26 MAY 1980


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## FOREWORD AND ACKNOWLEDGEMENT

This Final Phase IA Report is the main volume of the four volume TRW report on Evaluation DCS III Transmission Alternatives. These four volumes are:

1. Phase IA Report, Evaluation of DCS III Transmission Alternatives
2. Appendix A, Transmission Media
3. Appendix B, Regulatory
4. Appendix C, Regional Consideration and Characterization

The three above appendices present additional information which is intentionally omitted in the main report for clarity and balance.

Project work, as documented in the above noted Phase IA Report Evaluation of DCS III Transmission Alternatives and three appendices, has been performed by Defense and Space Systems Group, TRW Inc., and by TRW subcontractor, Page Communications Engineers, Inc., Northrop Corp., for the Defense Communications Engineering Center, Defense Communications Agency, under Contract No. DCA 100-79-C-0044.

This project has been managed by Dr. T. M. Chu and is supported by Messrs. G. J. Bonelle and S. H. Cushner; Dr. T. W. Kao; Mr. S. H. Lin; Drs. A. J. Mallinckrodt, E. W. Rahneberg, R. A. Smith and C. Y. Yoon; and by other TRW personnel on an as-required basis. Subcontracted work has been managed by Mr. J. C. Elliott and is supported by Messrs. I Benoliel, G. Dalyai, P. Ege, R. S. Graver, and R. Sadler.

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# 1.0 INTRODUCTION

This is the Final Report of the Phase IA effort of the "Evaluation of DCS III Transmission Alternatives" study conducted for the Defense Communications Engineering Center (DCEC), Defense Communications Agency (DCA) in accordance with Contract No. DCA 100-79-C-0044. It was performed by the Defense and Space Systems Group, TRW Inc. and by TRW's subcontractor, Page Communications Engineers, Inc., Northrop Corporation.

## 1.1 Purpose of the DCS III Study

The Defense Communications System (DCS), since its establishment in 1960 has been in a continuous process of growth and evolution. This process is a direct response to the changes of requirements and the advancement of communications technology. The DCS is currently in the transition period from first generation DCS (DCS I) to second generation DCS (DCS II). According to various project plans and schedule, the DCS II will be implemented during the period of FY 80 to FY 85 and will be fully operational by FY 85. DCS II will consist of AUTOVON, AUTOSEVOCOM, the integrated AUTODIN System (IAS), the upgraded and digitized terrestrial transmission system, and DSCS II/III systems. The DCS II will be the basis upon which the DCS III will be designed and implemented.

As a general rule, the life span of communications systems and electronics is about fifteen years. Therefore, by the year 2000, the DCS II equipment needs to be gradually replaced by either new units or newly developed units utilizing those new transmission media and/or communications technologies which are either currently being developed or would be developed from now to the year 2000. The result is the DCS III.

To provide a basis for the evolving architecture design of the third generation DCS for the years beyond 2000, it is necessary to identify alternative transmission media, communication technologies, system engineering concepts and designs. In addition, international, regional, and national regulatory barriers which may impact alternative media and transmission system designs also need to be identified and documented.

The primary objective of the DCS III study is the initial assessment and projection of transmission media which would be useful for DCS III in the years beyond 2000.

## 1.2 Scope of the DCS III Study

The DCS III study is composed of two phases and seven tasks as listed below:

1. Phase I:

   a. Phase IA:

      Task 1. DCS III Transmission Media Alternatives

      Task 2. Development of Evolving DCS Transmission System Alternatives

      Task 3. Identification of Technology and Regulatory Barriers

   b. Phase IB:

      Task 1. Comparative Evaluation of Alternatives

      Task 2. Relative Cost

2. Phase II:

   Task 1. Overlay of Special User Transmission Requirements

   Task 2. Reevaluation of Alternatives

Phase IA and Phase IB constitute the first year effort of the DCS III study and Phase II constitutes the second year effort.

## 1.3 Objective and Scope of Phase IA Effort

Phase IA consists of three tasks as indicated in the last section. The objective and scope of each task are presented in this section.

The objective of Task 1 of Phase IA is to identify promising transmission media for the DCS III time frame, to assess or forecast capability, to examine limitations and restraints, and to recommend needed research and development effort to resolve uncertainties in applications.

Brief but broad categorization and examination of all transmission media, either currently in use or under development, were conducted. After preliminary screening, sixteen media including airborne relay platforms, were deemed worthy of further investigation. These sixteen media were then grouped into four categories as tabulated in Table 1-1. The results of media investigation are documented in Appendix A.

The objective of Task 2 of Phase IA is to develop two candidate transmission systems employing appropriate transmission media for certain specified areas, satisfying the required capacities and connectivities of each area. Three areas of interest were selected for this purpose. These areas are Oahu Island of the Hawaiian Islands, a portion of the central Federal Republic of Germany, and Turkey. The alternative transmission systems proposed for these three specified areas are listed in Table 1-2. Six of the media were employed for alternative transmission system designs of Task 2.

The objective of Task 3, Identification of Technology and Regulatory Barriers, of Phase IA is self-explanatory. Related international, regional and national regulations, rules, procedures, standards, and recommendations which have impact on transmission system design were collected, organized, and reviewed. A summary and outline of regulatory barriers appear in Section 4. Appendix B provides detailed documentation to substantiate and supplement this summary and outline.

Technology barriers include current and forecasted hardware capabilities, propagational constraints such as fading and multiple path, bandwidth limitation, interference, etc. Technology barriers were investigated on the medium basis of the medium investigated and were documented along with each transmission medium.

In addition, general topographic and climatic conditions which affect transmission system design were collected for each of the three areas and are documented in Appendix C.

Table 1-1. Alternative Transmission Media Investigated

| | | |
|---|---|---|
| I. | Guided Waves | |
| | 1. | Coaxial Cable* |
| | 2. | Millimeter Waveguide |
| | 3. | Beam Waveguide |
| | 4. | Optical Fibers* |
| | 5. | Submarine Cables |
| II. | Radio Waves | |
| | 1. | Terrestrial Microwave Line-of-Sight Transmission |
| | 2. | Tropospheric Scatter Communication |
| | 3. | Millimeter Waves* |
| | 4. | EHF Satellite* |
| | 5. | Packet Radio |
| | 6. | Meteor-Burst Communications System |
| | 7. | *Radio Frequency Spectrum* |
| III. | Airborne Relay Platform** | |
| | 1. | Manned Unmanned Aircraft* |
| | 2. | Tethered Balloon* |
| | 3. | High Altitude Powered Platform |
| IV. | Miscellaneous | |
| | 1. | Alternatives to Electromagnetic Communication Links |

Note: *Media have been used for alternative transmission system design.

**Strictly speaking, airborne relay platforms are not transmission media but can be used to extend line-of-sight ranges. Investigation of such platforms has been specified in the Statement of Work for the DCS III study.

Table 1-2. Proposed Alternative Transmission Systems

| Specified Area | Proposed Alternative Systems |
| --- | --- |
| Oahu Island, Hawaii | 1. Millimeter Wave Relay System |
| | 2. Buried Cable System |
| | a. Option One - Coaxial Cable<br>b. Option Two - Optical Fiber |
| Federal Republic of Germany | 1. Airborne Communications System |
| | a. Option One - Tethered Balloon<br>b. Option Two - Aircraft |
| | 2. Buried Cable System |
| | a. Option One - Coaxial Cable<br>b. Option Two - Optical Fiber |
| Turkey | 1. EHF Satellite |
| | 2. Airborne Relay System |

## 1.4 Organization of Phase IA Report

This volume is the main report of the four volume report on Evaluation of DCS III Transmission Alternatives. These four volumes are:

1. Phase IA Report, Evaluation of DCS III Transmission Alternatives
2. Appendix A, Transmission Media
3. Appendix B, Regulatory Barriers
4. Appendix C, Regional Consideration and Characterization

The three above appendixes present additional information which is intentionally omitted in this main report for clarity and balance. The organization of the Phase IA Report is depicted in Figure 1-1.

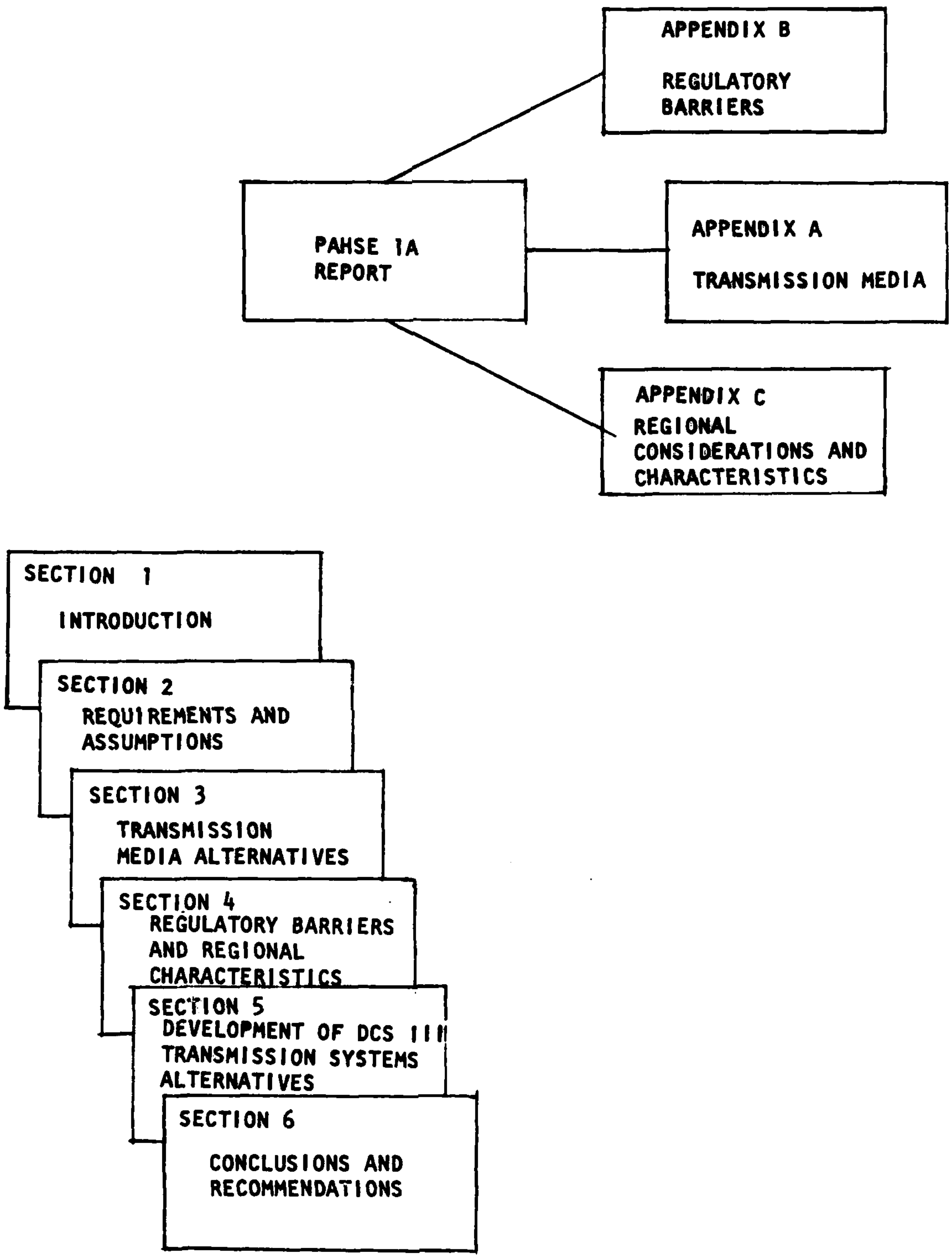


Figure 1-1. Organization of Phase IA Report

This main report is organized in six section of which this is Section 1, Introduction. Section 2, Requirements and Assumptions, summarized the communications requirement for each area of interest and the assumptions made to bound the scope of Phase IA effort. Section 3, entitled Transmission Media Alternative, presents a summarized result of transmission media investigation. Section 4 provides a brief description of international, national, and regional regulatory barriers and regional geographic and climatic conditions that affect transmission. Section 5 presents a baseline transmission system description, and two proposed transmission alternatives for each specified area of interest. Preliminary conclusive discussion on transmission media and research and development recommendations are provided in Section 7.

Appendix A documents results of transmission media investigations undertaken in connection with the Evaluation of DCS III Transmission Alternative Study. Results of detailed investigation of promising media are documented first, followed by a brief description of discarded media. The content of Appendix A is summarized in Section 3 of this volume.

Appendix B, Regulatory Barriers, presents a detailed review of rules, procedures, regulations, standards, and recommendations established by some international, regional, and national organizations and agencies. The purpose of this appendix is to substantiate and supplement the summary and outline of regulatory barriers presented in section 4.1 of this report.

Appendix C, Regional Considerations and Characterization, provides a description of the general topographic and climatic conditions which may affect telecommunications in the three areas of interest of the present study.

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## 2.0 DCS REQUIREMENTS AND ASSUMPTIONS

As indicated in the last section, two alternative transmission systems are required for each of the three specified areas using various promising media. The primary objective of these alternative system designs is the use of these designs as means to assess the real utilities of these media rather than design the alternative system.

However, communications requirements for each area have to be defined before system design can be commenced. This section presents the communication requirements for these areas and some assumptions made either for the requirements or the scope and aspects of the transmission system designs.

### 2.1 DCS III Requirements

The objective of this section is to present the projected DCS system in the year of 2000, hereinafter called the baseline, which will be used as communications capability required by that time, upon which the alternative DCS III transmission systems will be formulated. The communications requirements furnished for these areas are briefly summarized in the following subsections.

#### 2.1.1 Trunking Data

The preliminary data furnished were user requirements as shown in Tables 2-1, 2-2, and 2-3, for Oahu Island, Central Germany, and Turkey respectively. The information in these tables is trunking data which specifies only the number of voice channels between pairs of nodes and wideband data rate (if any).

From the information in these tables, a geographic trunking requirement is derived for each area. For example, Figure 2-1 shows a trunking circuit diagram of Central Germany.

Table 2-1. User Requirements of Central Germany

| | | |
|---|---|---|
| Borfink (BFK) | Sembach (SEH) | Landstuhl (LDL) |
| 24-LKF, 48-BAN, 36-MUL, 12-LDL, 24-HAN, 24-FEL | 24-WBN, 24-DON, 48-RSN, 24-BAN, 24,LKF, 12-PMS 24-MUL | 24-GAB, 24-PMS, 24-MUL, 24-BAN, 24-RSN, 24-VHN, 24-SGT, 48-DON, 48-FEL, 6.3 Mbps-RSN |
| Wiesbadn (WBN) | Kaserslauteen (KLN) | Langerkopf (LKE) |
| 24-FEL, 24-SEH, 24-HDG | 48-4SN, 24-ZBN, 48-BAN, 48-FKT, 48-BHR, 48-BDK, 24-ZBG, 24-KSL, 24-SCT, 72-HDG, 48-DON | 24-PMF, 24-ZWE, 12-ZBN, 24-SCH |
| Donnersberg (DON) | Koenigstuhl (KSL) | Zweibrucken (A) (ZBN) |
| 60-VHN, 24-CLO, 12-GAB, 24-LKF, 132-PMS, 108-RSN, 96-LDL | 48-SWN, 48-KRE, 24-MHN, 24-WMS, 24-KLN, 48-SGT, 12-ZBN, 12-LKF, 12-DON, 24-HDG | 24-ZWE, 24-PMS, 12-LKF, 24-KLN |
| Muhl (MUL) | Bann (BAN) | Zweibrucken (AF) (ZWE) |
| 24-BHR, 24-RSN, 24-SPM, 12-HAW, 24-LKF, 24-SCH, 24-SEH, 48-BIG | 24-FEL, 24-LDL, 144-RSN, 48-KLN, 24-SEH, 96-LKF, 24-PMS, 48-BFK, 24-SCH, 72-MUL | 24-ZBN, 24-RSN, 24-LKF |
| Lohnsfeld (LFD) | Schwelzinger (SWN) | Pirmasens (PMS) |
| 36-PMS | 24-HDG, 24-KBL | 24-ZBN, 24-SCH, 36-LFD, 12-LDL, 132-DON, 24-BAN, 24-SGT, 12-KSL, 12-HDG, 24-LKF |
| Ramstein (RSN) | Heidlberg (HDG) | Karlsruhe (KRE) |
| 24-SGT, 24-LKF, 24-BAN, 24-SEH, 24-ZWF, 24-KLN, 24-MLL, 24-LDL, 120-DON, 24-LSY, 6 Mbps-LDL | 24-PMS, 36-KLN, 108-DON, 24-FKT, 24-WBG, 48-SGT, 24-VHN, 24-KSL, 24-WBN, 48-KRE, 48-MHN, 24-SWN | 48-KSL, 48-HDG |

Note: Number indicates voice channels.

Table 2-2. User Requirement of Turkey

| | |
|---|---|
| Izmir (IZM) | Karatas (KTS) |
| 24-DAG<br>24-YAM | 24-DAG<br>24-MAL<br>24-INC |
| Yamanlar (YAM) | Malatya (MAL) |
| 24-IZM<br>24-SAH | 24-DKY<br>24-ERH<br>24-KTS |
| Sahin Tejesi (SAH) | Diyarbakir |
| 24-KAR<br>24-YAM<br>24-PAG | 24-MAL |
| Ankara (ANK) | Erhac (ERH) |
| 72-DAG | 24-MAL |
| Elmadog (DAG) | Incirlik (INC) |
| 72-ANK, 24-KTS,<br>24-SWP, 72-INC,<br>24-KAR, 24-IZM,<br>24-SAN | 24-KTS<br>72-DAG |
| | Sinop (SNP) |
| | 24-DAG |

Table 2-3. User Requirement of Oahu Island

| Circuit | Capacity (TI Channel) |
|---|---|
| Barber Point - Ford Island | 3 |
| Barber Point - Lualuali | 1 |
| Barber Point - Wahiwa | 1 |
| Bellows - Hickam | 2 |
| Bellows - Wahiawa | 1 |
| Barking Sands - Pearl Harbor | 1 |
| Camp Smith - Hickam | 2 |
| Camp Smith - Makalapa | 2 |
| Camp Smith - Pearl Harbor | 3 |
| Camp Smith - Wahiawa | 3 |
| Ewa - Wheeler | 2 (one-way) |
| Ford Island - Wahiawa | 5 |
| Fort Shaffer - Pearl Harbor | 1 |
| Fort Shaffer - Wahiawa | 2 |
| Hickam - Honolulu | 1 |
| Hickam - Pearl Harbor | 4 |
| Hickam - Wahiawa | 6, 6.176 Mbps |
| Hickam - Wheeler | 1 |
| Kaen Point - Wahiawa | 2 |
| Kokee - Wheeler | 2 |
| Kunia - Wheeler | 3, 7.136 Mbps, 3.191 Mbps, 3.360 Mbps |
| Laualualui - Wahiawa | 2 |
| Makaha - Pearl Harbor | 1 |
| Makalapa - Pearl Harbor | 2 |
| Molokai - Wheeler | 3 (one-way) |
| Pearl Harbor - Schofield | 1 |
| Pearl Harbor - Wahiawa | 7 |
| Schofield - Wahiawa | 1 |
| Wahiawa - Wheeler | 2 |
| | 68, 19.763 Mbps |

Note: 10 $\leq$ of VF equivalent circuits $\leq$ 20 = 1 T1 (approximate 20 to 60% expandability)

### 2.1.2 Circuit and Trunking File

Supplementing the trunking data as listed in tables and associated trunking circuit diagram derived from the data, a partial print of the DCA Circuit and Trunk File (Ref. 2-1) for these three areas was also made available. The file resides in DCA's computer. In the partial print, the following items are given for each voice or data circuit between any pair of nodes in these areas: agency requiring the circuit, purpose and use of the circuit, type of service, and circuit number. This partial print of the circuit and trunking file provides more useful information. Table 2-1 demonstrates information obtained from the file for a few circuits in Oahu Island. Due to the volume of such information derived from the file, completed data as shown in Table 2-4 derived from the supplied partial print is omitted.

### 2.1.3 DCS Connectivity and Multiplex Configuration Diagram

It is seen that the information provided by the circuit and trunk file is the circuits in use and that the trunking data as given in Tables 2-1 through 2-3 are installed trunking capacity. They supplement each other but are not necessarily the same. Both are current data and may not represent DCS system in the year 2000. To facilitate the study the following itmes were provided to TRW and Page for this effort.

Table 2-4. Information of DCA Circuit and Trunking File

| Circuit | File Information |
|---|---|
| Barber's Point to Ford Island | 12 Voice,<br>2 75-baud TTY<br>3 2400-baud data<br>2 9600-baud data<br>6 512-kbps data |
| Barber's Point to Honolulu | 2 Voice |
| Barber's Point to Pearl Harbor | 1 75-baud TTY<br>2 1200-baud data<br>1 120 scan WX fax data<br>1 50-kbps data |

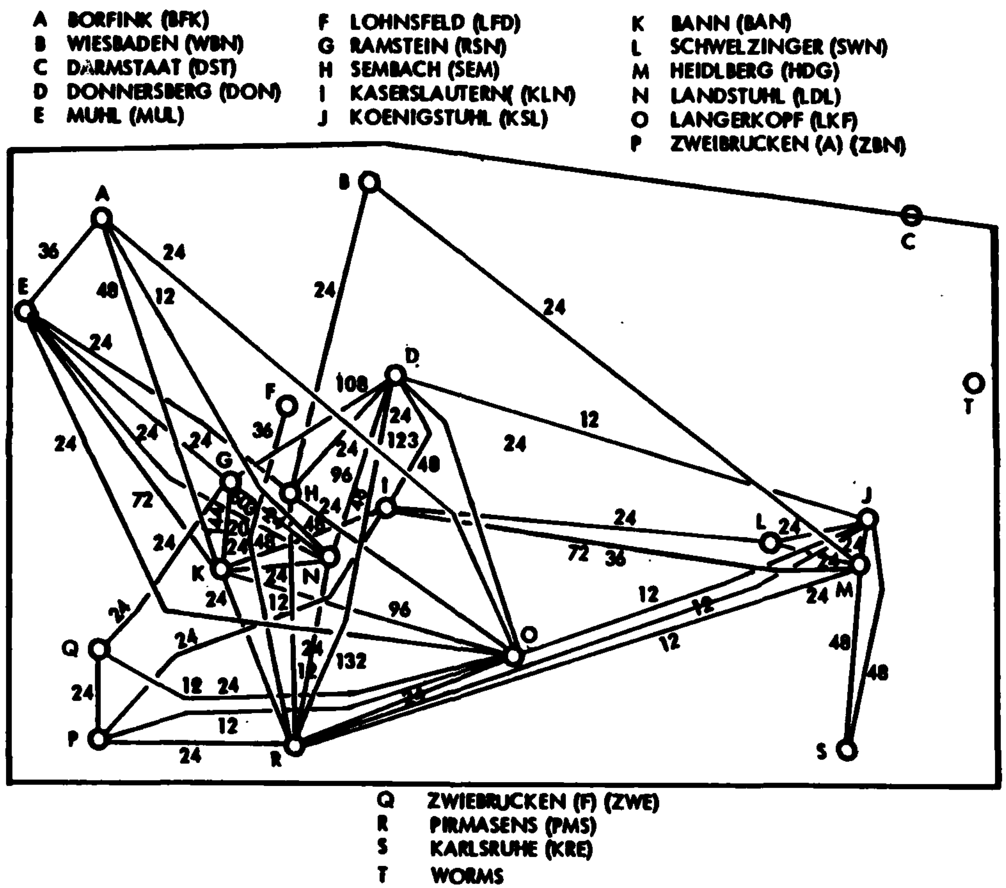



Figure 2-1. Trunking Circuit Diagram of Central West Germany

- Projected European DCA Connectivity 1985, DCA Drawing DCA-COM-CN-003
- European Defense Communications System, DCA Drawing E4R-COM-CM-005, sheets 1-5, 1 January 1979
- DCS Multiplex Configuration European Area, DCA Drawing EUR-COM-CM-007, 1 January 1979
- Digital European Backbone Multiplex Configuration, DCA Drawing DCA-SK-200-129, sheets 1-8, 27.January 1976.

The trunking data shown in Tables 2-1 through 2-3 were then modified and revised based on data obtained from about four sets of connection and configuration diagrams. To demonstrate the difference a modified trunking diagram for Central Germany is shown in Figure 2-1 for comparison. The difference is apparent.

### 2.1.4 Turkey and Oahu Requirements

Current DCS in Turkey depends heavily on troposcatter supplemented by microwave LOS relay. The planned digitized circuits in Turkey were obtained for the DCS Five Year Plan. Details are shown in Figure 5-36 and discussed in Section 5.5.1.2.

Due to lack of detailed circuit information for Oahu Island, the trunking requirements shown in Table 2-3 and depicted in Figure 5-3 were used as a basis for DCS II in the year 2000.

## 2.2 STUDY ASSUMPTIONS

The overall report and specifically the development of the DCS III alternative transmission system are heavily influenced by some assumptions. Among these assumptions, some are government directions, some are forced upon this study because of the communications requirement data, some are made to bound the scope of the study due to limited resources and time of performance period, and others are explicitly stated here to avoid possible confusion. Some major assumptions are:

1. The required communications capability is to support today's traffic, i.e. no major traffic growth or decay is anticipated.
2. Life span of communications equipment and electronics is taken to be from ten to fifteen years.

3. The current Digital Radio and Multiplex Acquisition (DRAMA) program equipment are assumed to be deployed for DCS II.

4. The TD-1192 multiplexer being deployed currently and the TD-1193 multiplexer being manufactured are assumed to be the standard multiplex schemes to be used in DCS II and will continued to be used in the DCS III time frame. It is further assumed that these multiplexers will be available for DCS III use.

5. Therefore the lowest digital data rate considered in this study is taken to be T1 channel rate, ie. 1.544 Mbps.

6. The network designs in these three specified areas of interest are treated as independent entities; no interconnection with other parts of DCS is considered.

7. This design study is limited to RF carrier capability because the communications requirement data available is only trunking information. Traffic statistics, such as calling rate, and conversion duration and their distributions, is lacking. Hence switching cannot be considered.

8. Hence, the objective of this study is the initial assessment and projection of transmission media which would be useful in the year beyond 2000. The merit of each of the alternative transmission media considered will be judged in the follow-on phase IB study from a point of view of practical utility through the comparison of various transmission system designs employing various promising media.

## 3.0 TRANSMISSION MEDIA

Various transmission including those currently being used, tested or developed have been examined for their potential utility for DCS III beyond the year 2000. The detailed results are documented in Appendix I Transmission Media of this report. This section presents a very brief summary of these media. The media which have been examined but not used for alternative system design are presented in Subsection 3.1, and others used in system designs are discussed in the Subsections 3.2 through 3.6.

3.1 Summarized Media Investigation Results. Various transmission media investigated can be categorized into four broad groups. These groups are guided waves, radio waves, airborne relay platforms, and miscellaneous. A brief summary of each medium not proposed for use in DCS III transmission alternatives is given in this section.

3.1.1 Guided Waves. Radio communications can be classified according to the propagation mechanism into two broad categories of guided waves and radio waves. In the case of guided waves, either a metallic or a dielectric guide is present along which the electromagnetic waves propagate. The guided waves investigated included:

- Coaxial cable
- Millimeter waveguide
- Beam waveguide
- Optical fibers
- Submarine cable.

Coaxial cable and optical fibers are the two media types employed for the proposed DCS III transmissions alternatives and are discussed in Subsections 3.2.2 and 3.2.5, respectively.

3.1.1.1 Millimeter Waveguide. The millimeter waveguide being developed currently in the U.S., Britain, France and some ther countries, utilizes a metallic circular tube with a diameter in the range of 50 ~ 60 mm. The $TE_{01}$ circular waveguide mode is used for transmissions where the attenuation decreases with frequency. The frequency band considered is in the range of 30 to 70 GHz with an available bandwidth of a few tens of GHz.

The system capacity is from 20,000 to 300,000 voice channels. Various forms of phase-shift keying have been employed. Repeaters with a gain of about 70 dB at a central frequency of 40 GHz are used with spacing varying from 20 to 60 km. It is a very large capacity system.

Since the diameter of the millimeter waveguide is many times the wavelength, hundreds of higher order modes can propagate simultaneously. This imposes attenuation, modal coupling, and dispersion problems. To minimize the conversion and re-conversion and to suppress the high-order modes, some special measures have to be used to construct the waveguide. Most commonly used measures are straight and precision tubing, dielectric lining, and helix construction. These measures make the millimeter waveguide costly. To keep the deployed guide straight and to use a large band radius further complicates the right-of-way problem and increases the implementation costs.

The basic research, development, and test of millimeter waveguide transmission system have been completed by Bell Laboratory in the 1960s. System testing and further refinement of millimeter wave transmission systems are presently in progress. However, it is apparent that this medium is a very large capacity and a very costly system. It is cost-effective only for a very heavy traffic trunk. Therefore, it may not be suitable for DCS III use in the near future

3.1.1.2 Beam Waveguide. Beam waveguide is another very large capacity transmission media. Either microwave band or light wave is used for transmission. The electromagnetic energy is confined in a tubular structure with one of the following three mechanisms for guidance: irises, lenses, or reflection mirrors. The ability of beam waveguide to guide an electromagnetic beam is severely limited by tolerance of the guiding structure; therefore, like the millimeter waveguide, beam waveguide requires absolute straightness, except for intentional bends. Any structure variation in temperature, aging, earth movement, or medium turbulance caused by temperature gradient increases beam attenuation. Experiments have been conducted in both microwave and optical frequencies, with typical attenuation of one dB/km or less for light transmission. It is a promising medium for long distance, heavy-traffic trunk needs. However, some technical problems such as long-term stability, automatic control, and alignment of lenses or mirrors and circuits await to be solved. Recent successful and fruitful technology advancements have produced optical fibers of compatible attenuation with less bulk and without stringent physical requirements; however, it does not appear that needed research and development work for beam waveguide are currently conducted with much enthusiasm. It is thus concluded that the application of beam waveguide to DCS III is certainly not in the DCS III time frame.

3.1.1.3 Submarine Cables. The submarine cables were extensively used in the 1950s and 1960s to carry transoceanic telephone traffic until INTELSAT Satellite I; however, even for the time being, various submarine cables still carry a sizeable intercontinental traffic.

Submarine cable technology has experienced vast advancement in the last four decades. The most recent advanced submarine cable, TAT-6, was completed in 1976 and connects the USA with Europe. This 6100 km cable, using SG submarine cable, jointy developed by the USA, Britain, and France, with 990 solid state repaters, 30 block equalizers and 5 shore controlled equalizers, carries 4200 high quality voice channels. A new submarine cable with a bandwidth of 125 MHz, in constrast with the 30 MHz bandwidth SG cable, is being developed now and plans for routes TAT-7 and TAT-8 have been discussed. This is because diversified telecommunications comprised of submarine cables and satellites is justified and mutually beneficial. Note that the 4200 circuit SG cable and the 5320 circuit NG cable in the Mediterranean Sea are compatible with the 6000 voice channel capacity of the current INTELSAT-4 Satellite. However, the planned life-span for a satellite is 5 to 7 years, but for a submarine cable it is 20 years. Actually, the TAT-1 Atlantic cable at the time of retirement in 1978 was still in operating condition and had been providing satisfactory service for 22 years.

It is anticipated that the use of optical fiber instead of coaxial cable, and the introduction of optical switching and processing will transfer the current point-to-point submarine cable system into an extensive undersea communication network.

3.1.2 Radio Waves. Radio waves media investigated are the following:

- Terrestrial line-of-sight transmission
- Troposphere scatter communications
- Millimeter waves
- EHF satellite
- Packet radio
- Meteor-burst communications system
- Radio frequency spectrum.

Millimeter waves, EHF satellite, and packet radio employed as DCS III alternatives transmission media are discussed in Subsections 3.3, 3.4, and 3.6, respectively. The rejected media are summarized in the following paragraphs.

3.1.2.1 Terrestrial LOS Transmission. Electromagnetic energy can be radiated in narrow antenna beams in UHF and EHF bands and especially in the frequency range of 1 to 10 GHz. Most terrestrial microwave transmission systems use line-of-sight (LOS) propagation between radio relay stations, typically resulting in approximately 30 mile distances between towers. In general, most LOS links presently in use operate between 2 and 8 GHz. The frequency carriers of present microwave LOS systems are mostly frequency modulated (FM) by a large number of voice channels, from 1500 to 3600 channels and up to 6000 channels with single sideband amplitude modulation (SSB-AM). In addition to the analog systems, there are the newer digital radio relay systems in which the carrier is digitally modulated by binary data ranging from 90 to 209 Mbps, with 1300 to 2900 voice channels digitized by pulse code modulation (PCM). Lack of available frequency band and demand for wider bandwidths results in expansion into the higher frequency range.

Some of the advantages of microwave LOS systems are;

- The atmosphere used as the transmission medium has an extremely wide transmission bandwidth
- Low interference because of high antenna directivity
- External noise is negligible

- LOS links are relatively easily implemented and modified
- Geographical barriers are easy to overcome
- Voice channels and video channels can be transmitted by the same equipment.

The disadvantages of LOS systems include the following:

- The number of VF channels or video channels that can be transmitted are limited by the available (assigned) frequency spectrum
- Transmission loss due to different types of fading, attenuation by rain, and other anomalous (abnormal) propagation
- Signal degradation due to different types of interference.

In many cases, microwave LOS system performance is limited by natural parameters of the transmission medium such as the following:

- Attenuation by rain, snow, hail, clouds, etc.
- Scattering by irregularities in the refractive structure of the atmosphere
- Refraction, ducting, and multipath resulting from atmospheric layers
- Dispersion resulting from frequency-dependent properties of the lower atmosphere
- Reflection, scattering, multipath resulting from irregular terrain and man-made structures.

The above limitations are usually overcome by using directive antenna, space diversity (including height diversity), frequency diversity and polarization diversity. Frequency coordination is required for the systems operating in frequency bands which are shared with satellite communications systems.

3.1.2.2 Tropospheric Scatter Communication. The non-homogeneous structure of the troposphere is capable of scattering high frequency electromagnetic energy. In a troposcatter system, a transmitting antenna and a receiving antenna are spaced at a distance much longer than the line-of-sight range and pointed to a common scattering volume in the troposphere at the mid-point of the great circle path. A troposcatter communications system usually operates with high transmitting power and a large high gain antenna. However, increasing antenna size beyond a certain limit, diminishes the antenna gain increase by a factor related to the ratio of the scatter angle to the antenna beamwidth called aperture-to-medium coupling loss.

Typical troposcattering communications systems allow transmission up to 120 voice channels in the 100 MHz to 5 GHz frequency range. One tropo span is usually limited to 600 miles (1000 km). Troposcattering systems presently operate in the preferred frequency bands of 100, 400, 450, 750, 800, and 900 MHz and 1.8, 2, 4, and 5 GHz. Typical transmitter powers are from 5 kW to 50 kW, and receiver noise figures range from 2 dB at 900 MHz to 9 dB at 5 GHz. Typical antenna diameters are 10 to 120 feet maximum. Frequency diversity and space diversity are commonly used.

Troposcatter communications have been developed into a highy successful method of radio communications which provides the following advantages not offered by other media:

- High grade multichannel service over 50 to 600 mile distances in a single span
- High propagational reliability on a year-round basis with a properly designed system
- Capability for use in rugged or otherwide inhospitable terrain, or over a stretch of water where other means of communications are impractical or impossible
- Relatively high degree of security compared with other communication methods
- Minimal deliberate or unintentional interference unless interfering transmission is within beam and range of other troposcatter systems.

Disadvantages associated with the troposcatter systems are:

- Very large antenna system
- Higher power transmitters required for transmission
- Limited bandwidth due to frequency-selective fading caused by multipath propagation
- Limited communications range.

Although most existing tropscatter links employ frequency division multiplex and frequency modulation, development of high-rate digital transmission techniques for LOS and satellite communications has led to interest in considering similar techniques for troposcatter links. This interest is heightened by the need for encryption as well as by the desire to integrate troposcatter systems into larger digital nets. Currently, some research and development for digitizing troposcatter systems is in progress.

3.1.2.3 Meteor-Burst Communications Systems. A meteor-burst communications systems (MBCS) is a medium range system operating at VHF (30 - 300 MHz) band that can provide a rapid, scure, two-way digital communications service. Other types of services such as voice and facsimile, although they have been tested, have not yet been implemented. MBCS operation is based on the use of the meteoric forward-scattered wave phenomenon induced by the ionized trails left behind by meteors penetrating the lower ionosphere. These forward-scattered signals reach a distance far beyond the usual line-of-sight range because of the high altitude of these trails (80 -11 km). A meteor scatter signal, in general, is much stronger than an ionspheric and a tropospheric scatter signal. A MBCS, consequently, is a lower-power, and a lower-transmitting rate system in contrast with the scatter system.

Initial investigation of the feasibility of using meteor-scattered waves for communications, design and development, system evaluation, and testing was conducted in the USA and Canada in the years immediately after World War II, and this pioneer work was declassified in 1957. The well-known Canadian JANET system was developed in this period and was operational in 1954. Transmitters at both ends of a JANET system transmit carrier continuously on different frequencies spaced typically one MHz apart with the frequency band of 30 to 50 MHz When the received signal-to-noise ratio has risen to a pre-determined value due to a formed meteor trail, the stored message is then transmitted until the signal-to-noise ratio falls below this value. The JANET system used separate arrays of four 5-element Yagi antennas for transmitting and receiving. The transmitter power was 500 Watts. The average information rate was 34 words per minute and the individual hourly means of the rate varied widely. The average character error rate was less than 0.1 percent.

Recently the Supreme Headquarters Allied Powers in Europe (SHAPE) Technical Center (STC) has developed a meteor-burst system called Communications by Meteor Trails (COMET), which incorporates both diversity reception and automatic request for repeat features. The COMET system is designed to provide two-way TTY and data transmission between two ground stations at a maximum spacing of 2000 km. The information is transmitted in frequency shift keying (FSK), with a total frequency deviation of 6 kHz at a signalling rate of 2000 baud. The receiving terminal uses a combination of frequency and space, or height diversity. The COMET system has been intensively tested over a 2000 km path for several years. Transmitter power was 500 watts, and the frequencies used were 56 and 39 MHz, one for each direction. The hourly average data rate varied from 40 to 240 baud in unfavorable periods and 50 to 680 baud in favorable periods. The error rate was less than one in 3000 characters.

The MBCS has some special features, one of which is survivablity in a nuclear environment. The lower data rate and the intermittent transmission make it unsuitable from DCS use. Also the possibility that the data rate or bandwidth can be raised by a few orders of magnitude is highly unlikely.

3.1.2.4 Radio Wave Spectrum. Finally, the whole radio spectrum was examined from the lower ELF end to the higher EHF end to search for any potential frequency band useful for DCS, but missed in early screening process. No promising electromagnetic media worthy of further investigation resulted from this search.

3.1.3 Airborne Relay Platform. A wideband communications need, such as multiple analog or digital voice channels, high rate data channels, fascimile, etc., can only be fulfilled by using a high radio frequency as a transmission medium. This is because of either the bandwidth limitation imposed by the propagation mechanism or the ITU radio frequency regulations. Radio waves in the UHF range or beyond only propagate along a line-of-sight path, hence the range is severely limited. Spacing between two adjacent microwave relay stations is about 30 miles, depending on the local terrain condition and the height of antenna towers used.

One way to extend the local line-of-sight horizon is to use an airborne relay platform. Various kinds of airborne platforms which have either been proposed, tested, or are in use, include:

- Manned aircraft
- Unmanned aircraft, i.e., remotely piloted vehicle (RPV)
- Tethered balloon
- High altitude power platform
- High altitude power glider
- High altitude floating balloon
- Rocket or missile
- Cruise missile
- Parachute.

By preliminary examination, only the first four platforms are suitable for long haul day-to-day communications needs. Results of investigations are given in Section A.14, Manned and Unmanned Aircraft, Section A.15, Tethered Ballon, and Section A.16, High-Altitude Powered Platform Characteristics and Capability, respectively. See Appendix A, Transmission Media of Final Phase IA Report. The following paragraph briefly summarizes the high-altitude powered platform (HAPP).

The proposed HAPP is either a balloon or an aircraft stationed or orbited over a station at an altitude of 20 km (70,000 kt) for a duration on the order of a year. The operating altitude of 20 km was chosen primarily because wind velocities within the continental United States usually are at their minimum at this altitude. Both of these platforms would be free-flying and would receive their power for stationkeeping via a microwave beam directed upward from the ground. Two HAPP baseline designs are tabulated in Table 3-1.

Table 3-1. HAPP Baseline Airship Design

| Characteristics | Design A | Design B |
|---|---|---|
| Payload (kg) | 130 | 720 |
| Hull Mass (kg) | 34 | 611 |
| Rectenna Mass (kg) | 278 | 525 |
| Car Motor (kg) | 134 | 214 |
| Volume ($m^3$) | 14,000 | 37,000 |
| Fineness Radio | 4 | 4 |
| Power (kW) | 31 | 46 |

It is seen that the design A with payload 130 kg would be suitable for high altitude relay needs.

The unique feature of the HAPP is the microwave power system which consists of a ground station and a rectenna on the balloon/aircraft. The ground station converts conventional electric power into microwave power that is focused into a narrow beam by the transmitting antenna. The beam is then intercepted by a rectenna (a rectifier/antenna combination on the balloon/aircraft) comprising a large number of small antennas which feed a rectifier circuit that coverts power from the microwave beam to DC power.

The HAPP looks very promising for communications applications. Because of its higher altitude (higher than an aircraft or a tethered balloon), a HAPP can be used to provide a larger cover area or high elevation angles of line-of-sight paths for the same covered area. The high elevation angle is of particular interest for higher frequency application because the rain attenuation of radio waves is substantially reduced. However, the HAPP is still under development and is not recommended as an airborne relay platform in this study.

3.1.4 Miscellaneous Media. Some transmission media other than electromagnetic waves were also examined. They include:

- Gravitational waves
- Subnuclear particle beams.

It was concluded that these cannot provide useful communication support for DCS III. However, the study results are documented in Section A.13, Alternatives to Electromagnetic Communication Links, of Appendix A, Transmission Media, or Final Phase 1A Report.

3.2 Coaxial Cable. Coaxial cables are used to transmit electromagnetic signals in the TEM propagation mode. The outer and inner conductors are usually copper with a dielectric medium separating them. To add mechnical strength as well as to provide additional magnetic shielding, lead to steel tapes are applied over the outer conductor. Also, additional dielectric insulation is wrapped around the outer conductor. The outer conductor serves as shielding between adjacent transmission channels due to skin effect of the good conductor, thus reducing the crosstalk and interferences.

While the 9.5 mm (3/8") coaxial cable has been the only standard cable used in U.S., in European countries the 2.6/9.5 mm cables are used in the high capacity 12 MHz and 60 MHz systems, and the 1.2/4.4 mm cables are used in 1-12 MHz.

Coaxial cable has been extensively employed to carry telephone traffic either locally or over the U.S. continent. As the demand increased and the technology advanced, the Bell L-system grew from the 600-channel vacuum tube L1 to the most advanced 13,200-channel transistorized and microprocessor-controlled L5E.

The broadband signal, either analog or digital, can be transmitted over a coaxial cable. Although economic reasons as well as high channel capacity per cable have favored the analog FDM type signal in the past and even at the present, the significant progress realized in digital techniques and semiconductor integrated circuits render digital transmission economically feasible. The North American digital hierarchy is based on the 64-kbps PCM digitized voice band. The transmission rates for the multiplex levels from one to four are 1.544, 6.312, 44.736 and 274.176 Mbps, respectively, corresponding to 24, 96, 672, and 4032 voice channels.

A summary of the state-of-the-art of the coaxial cable system is given in Table 3-2, from which it may be seen that the most advanced analog system is the Bell L5E system covering a bandwidth of 60 MHz with a capacity of 13,200 voice channels. The most advanced digital system is the Japanese NTT PCM-400 Mbps system with a capacity of 57,000 vice channels. Expectation regarding future expansion of the coaxial cable system capability is also noted in Table 3-2.

Table 3-2. Summary of the State-of-the-Art Coaxial Cable Transmission Systems

| Cable Size | 1.2/4.4 mm | 2.6 mm or 3/8" |
|---|---|---|
| Data Rate | 140 Mb/s (1)<br>12 MHz (2) | 400 Mb/s (3) 60 MHz<br>63 MHz (4) |
| Repeater Spacing | 2 km | 1.55 km 1 Mile |
| Capacity Voice Channel | 1920 2700 | 57600 10800 13200 |
| Future Capabilities | 18 MHz | 565 Mb/s = 800 Mb/s<br>120 MHz |
| Remarks | (1) Digital Systems in Europe<br>(2) Analog System in Europe and Japan | (3) Japanese PCM-400 System<br>(4) Bell L5E |

3.3 Millimeter Waves. The mm wave band between 30 GHz and 300 GHz (and above) has been receiving considerable attention in the last few years. This has produced significant technology advancements. Applications involving line-of-sight (LOS) propagation through the earth's atmosphere are limited to relative short distances due to well-known atmospheric effects. Even with the range limitations for all weather, ever-increasing demand for new spectral space coupled with technology advancements promise to ultimately result in development of mm wave LOS communication systems. Technology is already sufficiently developed for deployment of high performance LOS communications systems operating in the mm wave band. The capability of already available mm wave components is well beyond present requirements so that any deployment promises to satisfy needs well into the future.

Projection of actual use will depend more on need than feasibility. This view is substantiated by the history of a high performance mm wave communication set which was developed in the early 1970s. This is the GRC-173 radio set which, operating near 10 mm in wavelength, was developed by the Air Force during the early part of the 1970s. It is powered by a 100 miliwatt semiconductor, uses a 6-foot parabola antenna, and the receiver has a 11 dB noise figure. This equipment used bi-phase modulation at data rates up to 250 Mbps and operated as expected. It was never placed in permanent service for lack of a requirement.

Sources of millimeter wave radiation are currently available in one form or another with power capability ranging from milliwatts up to several hundred kilowatts. One kind of mm source is travelling wave tubes (TWT) which are currently under development in the frequency range from 20 to 50 GHz with output power varying from a few watts to a few kilowatts. The current available TWT from Hughes at 39 GHz with a minimum power output of 2 watts and gain 40 dB is powerful enough for MM wave LOS need. The Gyrotron which is currently being developed in the USA and USSR is a very high powered device capable of delivering a few kilowatts or more power.

It is developed for some other purpose than communication. Other low power sources include field effect transistor (FET), impact-avalanche transit time (IMPATT) device, transferred electron device (TED) also called GUNN device (named for the inventor); these devices are currently being developed and tested in various laboratories over the world. TED, FET, and IMPATT devices currently can generate about one watt continuous power. Parallel operation of these devices to raise the power level to ten watts are being tested. These devices can be modulated directly by varying the supply voltage or bias. Modulation at a rate of 300 Mbps has been reported using PIN diodes at 40 to 119 GHz. If advancements continue, 2 Gbps modulation rate should be feasible at frequencies up to 100 GHz.

Similarly, progress is expected for millimeter wave receiver technology. In 1973 transmitter amplifiers were available with 3 dB noise figures at frequencies up to about 8 GHz; by 1990 it should be possible to obtain narrow band transistor amplifiers with 3 dB noise figures at 40 GHz. Current "off-the-shelf" Schottky diodes can be used as a mixer with a 6.9 dB single side band noise figure at 50 GHz. Field effect transistors (FET) are tunnel diode amplifier devices commercially available in 1978 have the noise figures of a few dB in 10 to 30 GHz. Reduction of noise figures in high frequencies is expected. There a number of high performance receiving devices which require cryogenic temperatures. These may not have much application to LOS communication on the Earth's surface since the antenna temperature is on the order of 300° K, limiting the maximum improvement to a few dB.

The major restriction for millimeter wave application is the atmospheric effects which show up in these ways:

- Wave attenuation
- Scintillation or rapid fading
- Beam refraction which may show up as long-term fading

Wave attenuation can result from energy loss from the main beam due to scatter from rain drops or energy due to absorption caused by molecular resonances of oxygen and/or water vapor in the atmosphere. Scatter due to rain can also show up as a change in polarization which is of primary concern in systems that use each of two orthogonal polarizations to double the channel capacity. Attenuation is also associated with an increase in antenna temperature to as high as the environmental temperature.

Scintillation or rapid fading is caused by multipath interference between waves travelling over slightly different paths. Different paths can be caused by globules of non-homogeneity in the refractive index of the atmosphere which break up a wave and defractioon or refract components into slightly different directions.

Beam defraction always exist for horizontal beams due to the transverse gradient in the refractive index of the atmosphere. This is associated with altitude dependence of the refractivity of the atmosphere. The beam could, at times, end up displaced above or below the receiving antenna so that a narrow beam would essentially miss the receiving antenna. The effect would be long-term fading unless an adaptive system is used which corrects for this effect.

The frequency congestion in the band of 1 to 10 GHz and the rapid progress in millimeter wave technology lead to the development and deployment of millimeter wave communications systems. It is anticipated that these systems will be in popular use by the year 1990 and beyond. However, well-planned system design and test programs are needed to further enhance the progress of the state-of-the-art.

3.4 <u>EHF Satellite Communications</u>. The demand for satellite communications services is continually increasing and the capacity available within the 500 MHz frequency bands presently used at 6 and 8 GHz will not be sufficient to meet future needs. Therefore, additional spectrum space will be required with future systems and this can be provided by using frequencies above 10 GHz, where larger bandwidths are available.

The design of both satellites and earth stations in the higher frequency bands will not be significantly changed from those at lower frequencies and no major difficulties should arise due to the great amount of technology available concerning millimeter-wave circuitry. The other problem, which has hitherto inhibited the use of EHF communications, the comparatively high attenuation under bad weather conditions, may be overcome by the higher antenna gains achievable and diversity reception. Thus it would appear that as the limited spectrum space and number of available positions in the synchronous equatorial orbit becomes saturated, the advantages of the EHF band will become irresistible. These include:

- Extra (wider) bandwidth - 1 GHz at 20, 30 and 40 GHz
- Higher gain, small antennas
- Jamming threat less effect
- Smaller spacing between satellites in the same orbit is feasible.

Multiple beam antennas (MBAs) with jammer nulling and/or beam steering offer significant improvment in uplink electronic counter-counter measure (ECCM) performance at the higher frequencies since much smaller beamwidths are available for areas such as the European theater without excessive antenna sizes. As an example, an 0.75° beamwidth is available from a 3 ft. antenna aperture at 30 GHz. The same beamwidth at 7.5 GHz wuld require a 12 ft. antenna which is not very practical for use in space, particularly since several may be required to cover different areas (e.g., Europe, CONUS and the Middle East).

Current MBAs, such as have been designed for DCS III are inefficient and may not be suitable for use at EHF where they may be even more lousy. However, recent advances in the design of offset feed antennas apear to be capable of meeting the more stringent requirements of the higher frequency bands.

The anti-jamming (AJ) performance could be increased considerably over that available in the 7-8 GHz frequency bands if full advantage is taken of the total bandwidth available for maximum band spreading, i.e., 1 GHz. This is beyond the capability of current AJ modems of the frequency hopping or direct sequence types but hybrid modems using a combination of frequency hopping and pseudorandom noise direct sequence band spreading appear to offer an economical solution.

Further improvements in AJ performance can be obtained by the use of an on-board processing which will also provide better control of traffic flow and simplify routing without the use of excessive downlink microwave power resulting from broadcasting point-to-point traffic.

A SATCOM transponder system could play a very important role in long-haul communications for DCS. Another advantage of EHF communication systems is that it is less vulnerable to jamming threat and smaller spacing between satellites in the already crowded orbit. The 30 GHz (uplink) and 20 GHz (downlink) bands would provide adequate performance with an availability of better than 99%. Greater availability, say on the order of 99.99% could be obtained using two terminals spaced about 30 miles apart with ideal line-of-sight radio or fiber optics link. Suitable technology has been demonstrated in the laboratory and a number of development programs are under way to produce space qualified hardware.

3.5 Optical Fibers. Use of optical fiber for communications media was proposed in 1966. Although the best existing fiber was characterized by greater than 1000 dB/km attenuation at that time, it was speculated that losses as low as 20 dB/km would be available and it was suggested that such fiber would be useful for telecommunication. This anticipated 20 dB/km fiber was realized in 1970, and from then on progress in the field of optical fiber transmission has been rapid. Two excellent examples of progress in the field are the reduction of loss in optical fibers and the reliability improvement of the semiconductor injection laser, the transmitter of an optical fiber communication system.

The losses in an optical fiber operating in the wavelength range of 0.8 to 0.9 m has been continuously reduced from 1000 dB/km in 1968, to 100 dB/km in 1969, 20 dB/km in 1970 and 1.6 dB/km in 1976. Because of the near zero dispersion of single-mode, step-index fiber operating in the wavelength range of 1.2 to 1.4 μm, the recent research and development emphasize the fibers, optical sources, and photodetectors operating in this range, optical fibers with losses of 0.47, 0.16, and 0.2 dB/km have been reported already.

In the same period the reliablity of the AℓGaAs injection laser also has been greatly improved, the projected room temperature mean life being in excess of a million hours based on accelerated temperature test. The photodetectors, needed for optical fiber systems, had already been developed, for fiber communications studies were initiated in 1971. Additional development in this area accomplished over the past decade has mostly been concerned with optimization of existing technology for use with the anticipated data format.

3.5.1 Optical Fiber Communications System. Some milestones of optical fiber communications development are tabulated in Table 3-3. Due to the rapid component development that has taken place, some optical fiber communication systems have been fielded not only for test but also for actual carrying of commercial traffic. Table 3-4 lists a few representative systems.

An optical fiber communication system consists of a transmitter, a receiver, and an optical fiber connecting the transmitter and the receiver. For a long link, one or more repeaters for analog signal or regenerative type repeaters for digital signal are employed

Figure 3-1 depicts an optical fiber communications system.

3.5.2 Optical Fibers. Various kinds of optical fiber are available. The major ones are:

- Graded-index fiber
- Multi-mode step-index fiber
- Single-mode step-index fiber.

Table 3-3. Milestones of Optical Fiber Communications Development

| Event | Time |
|---|---|
| Ruby laser demonstrated, optical communications suggested | 1960 |
| Fiber communications proposed | 1966 |
| Low loss fiber (20 dB/km) available | 1970 |
| Light source reliability ($10^6$ hr) improved | 1977 |
| Photodetector for long wavelength developing | Present |
| Commercial field test system | 1977 - Present |

Each of these three major types of optical fiber has a core and a region of lower refractive index cladding the core. Depending on how the refractive index varies within the core, the fiber is described as either step-index type or graded-index type. A fiber can support many different guided modes of propagation. Each mode has its own phase velocity and its own field distribution on a cross-section plane.

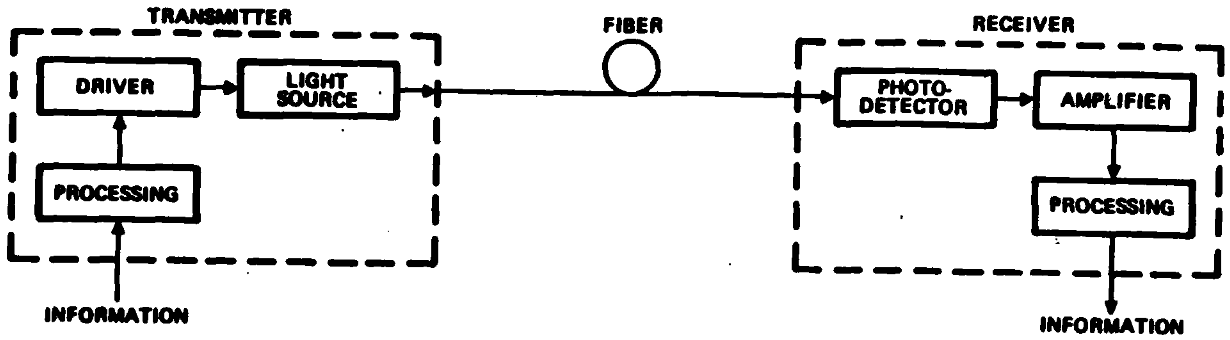
The most important fiber characteristics are attenuation and dispersion. The major mechanisms which contribute attenuation for waves propagation along the fiber are absorption losses, scattering losses, and radiation losses. The absorption losses in a fiber can be grouped into three categories, intrinsic absorption, extrinsic absorption, and atomic defect absorption. Intrinsic absorption is the power of transmitted light lost in the fiber material as heat. Extrinsic absorption is caused by some impure material in a fiber such as metal ions and hydroxyl (OH). This absorption has been greatly reduced by processing control of the basic material of optical fiber. Further improvement is expected. Scattering losses are causes by density and refractive index variations within the fiber material; these variations are due to frozen-in thermal fluctuations of constituent atoms. The intrinsic scattering losses set the fundamental

Table 3-4. Representative Test and Operational Optical Fiber Systems

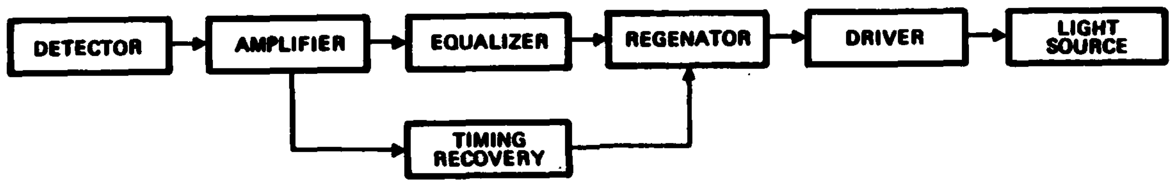
| Nation | Data Rate (Mbps) | Total Length/ Repeater Spacing (km) | Date (Month/Year) | Location |
|---|---|---|---|---|
| USA | 1.544 | 9/3.7 | April 1977 | Long Beach, California |
| USA | 44.7 | 2.8/2.8 | June 1979 | Phoenix, Arizona |
| Canada | 6.3 | 6/1.5 | Oct. 1977 | Montreal, Canada |
| Canada | 274.0 | 52/3.5 | Nov. 1979 | Alberta, Canada |
| Japan | 32.0 | 18/18 | Sept. 1978 | Tokyo, Japan |
| Japan | 800.0 | 7.3/3.2 | April 1979 | Tokyo, Japan (1.3 μm) |
| England | 8.0 | 13/13 | Dec. 1976 | Surfolk, England |
| England | 140.0 | 13/6 | Dec. 1976 | Suffolk, Englad |
| Italy | 140.0 | 9/9 | Sept. 1977 | Turin, Italy |

attenuation limit in fibers. The scattering losses follow the Rayleigh law - inversely prorated to fourth power of wavelength - therefore fiber optics research and development effort has been shifted from the 0.7 to 0.9 μm to 1.2 to 1.5 μm. Radiation is another loss usually associated with fibers caused by microbend. Bend-inducted radiation loss can be significantly reduced by using bends with large radius of curvature.

Communication transmission capacity of a fiber depends on fiber dispersion characteristics. Dispersion effect, broadening the light pulses propagating along a fiber, limit either the bandwidth of transmission or the spacing of repeaters. There are three major components of dispersion; namely, waveguide dispersion, modal dispersion, and material dispersion. The fiber material is dispersive if its refractive index does not vary linearly with wavelength. This implies, physically, that the phase velocity of a plane wave propagating in such material varies nonlinearly with frequency and, consequently, a light pulse will broaden as it propagates. Pure silica and several doped silica fibers exhibit zero material dispersion near the wavelength of 1.3 μm. The other important dispersion, particularly for single-mode step-index fiber is the waveguide




a. Optical Fiber Communication System Without Repeater




b. Repeater of an Optical Fiber Communication System

Figure 3-1. Optical Fiber Communication System dispersion which is due to the phase constant of propagation and is not linear with wavelength; thus the group velocity varies with wavelength. This kind of fiber wavelength is dispersive and broadens a transmitter pulse. However, at a wavelength of about 1.3 μm the material dispersion exactly cancels the waveguide dispersion. At this wavelength, the bandwidth of a single-mode fiber is enormous (100 GHz/km). It is fortuitous that the minimum attentuation also occurs in this spectral region. The third kind of dispersion, called modal dispersion, only occurs in a multimode fiber along which different modes propagate with different group velocity. The modal dispersion can be dramatically reduced and, hence, the bandwidth improved by grading the fiber index in a parabolic fashion which tends to equalize the group velocities differences.

3.5.3 Optical Sources. The sources used for fiber optical communication systems are light emitting diode (LED) and solid state laser diode (LD). These sources should be capable of stable, continuous (CW) operation for long times and of size and configuration compatible with the optical fiber. The power output of these sources is not the most important consideration, however, these sources must be capable of coupling at least microwatts, and preferably a milliwatt or more optical power into a transmission fiber.

In general, LDs offer the advantage, as compared with LEDs, when narrow spectral bandwidth, about 20 Å or less is used, which is also a very useful region for minimizing the effect of fiber dispersion. Lasers also can be modulated up to a rate of a few hundred megahertz and can be coupled to a fiber because of relatively directional emission. Lasers are now considered primarily for use in single-mode fiber systems. In contrast, incoherent LEDs offer inherent advantages of simplicity of construction and operation, and thus the expectation of long trouble-free operational life. From previous discussions on fiber attenuation and dispersion, it is seen that the wideband incoherent sources must operate at 1.2 to 1.4 μm wavelength where both fiber attenuation and dispersion are low.

Both surface-emitting diodes and end-emitting diodes can provide several milliwatts of power output on the 0.8 to 0.9 μm range, when operated at drive currents of 100 to 200 mA. The spectral width of the output of an LED operating at room temperature in the 0.8 to 0.9 μm range is usually 250 to 400 A at 3 dB points and 500 to 100 Å for material with smaller energy gap operating in the 1.1 to 1.3 μm wavelength region. This broad radiation spectrum limits the bandwidth.

An LED becomes a laser at high current densities by adding a cavity to provide feedback. The optical feedback in a laser diode can be obtained by clearing the parallel facets to form the mirrors of the Fabry-Pert cavity. Many different laser diode structures have been fabricated and tested. The double heterojunction (DH) laser diode is the most widely used continuous wave source for optical communications. A stripe geometry is commonly used for DH injection lasers. For a laser operating in the fundamental transverse mode, the beam width in the plane of the junction is typically 5° to 10° and varies only slightly with diode topology and internal geometry. At least one-half of the power emitted can be coupled into a fiber with a core diameter of tens of microms. Most narrow-stripe laser diodes operate with several longitudinal modes and therefore emit over a 10 to 30 Å spectral width.

The output of a LED can be modulated by varying the drive current. The output is linear with the current over a very wide range from a few to hundreds mA. The modulation bandwidth is limited by the carrier combination time, which can be reduced either by decreasing the thickness of the active lasing layer at low doping level or by increasing the active layer doping level. For surface emitting diode, increasing bandwidth is commonly achieved by heavy doping and/or high carrier confinement. However, both methods decrease the diode efficiency. Hence, the power-bandwidth product of DH lasers with doping level greater than $10^{18}$ per cm is almost constant. Semiconductor lasers can be directly modulated by varying the drive current. Because the laser output is proportional to the drive current over a broad current range above the threshold level, both analog and digital modulation can be used. Because of the short recombination lifetime of the carrier, less than $10^{-8}$ seconds, the modulation bandwidth is expected to be up to a few gigahertz. Table 3-5 compares the two basic optical fiber communications light sources.

Table 3-5. Comparison of Light Sources

| | LED | LD |
|---|---|---|
| Spectral bandwidth | Wide ~ 35 nm | Narrow < 2 m, |
| Coupling efficiency | Low ~ 100 μ W | High ~ 1 mW |
| Structure | Simple | Complicated |
| Temperature difference | Weak | Strong |
| Modulation | Low 50 ~ 200 MHz | High 500 ~ 1000 MHz |
| Remarks | Short wavelength, commercially available, field tested | Reliability to be established, relaxation oscillation and self-pulsation problems |

3.5.4 Photodetectors. At the receiving end of an optical fiber communications systems, an optical detector or photodetector is employed to convert optical signals to electronic signals which are subsequently amplified and processed. The fundamental process of a photodetector is to generate an electron-hole pair while a photon hits the depletion layer of the detector. The ratio of carrier pairs generated to the incident photon is usually referred to as quantum efficiency. To have high efficiency, the depletion layer must be sufficiently long. On the other hand, because long carrier draft times limit the speed of operation, hence the modulation bandwidth, a thin depletion layer is preferred. Therefore, there is a tradeoff between quantum efficiency and speed of operation.

The two commonly used photodetectors are PIN photodiode and avalanche photodiode. At long wavelenghts, where light penetrates more deeply into the depletion, front-illuminated PIN photodiodes with wide depletion layers are preferred. In the wavelength range of 0.8 to 0.9 μm, high quantum efficiency in the order of 80 to 90 percent and response time as short as 1 nsec have been achieved. At wavelengths of 1.0 μm or longer, side-illuminated silicn photodiode is used. The response of germanium photodiodes spans the entire frequency range of interest for fiber optics communications, but the relatively high dark current remains a problem. However, experimental silicon PIN diodes with good efficiency and large bandwidth have been built and are now commercially available.

An avalanche photodiode (APD) provides' internal amplification mechanism to increase detector output in order to overcome the thermmal noise of the following amplifier. The doping profile is so adjusted to result in a narrow region where very high electric fields exist. Carriers which drift into this region can be accelerated to velocities of sufficient magnitude to generate new electron-hold pairs through the process of collision ionization. The multiplication of carriers is random with average carrier multiplication of tens or hundreds being possible. A comparison of these two photodiodes is given in Table 3-6.

3.5.5 System Capablities and Research Trends. The advantages of utilizing fiber optics, as previously discussed, which will drive changover from cable and microwave relay systems to the fiber optic system, can be summarized as follows:

- Very high bandwidth; billion bit per fiber capacity available at low cost by the late 1980s
- Greater bandwidth/volume; orders of magnitude more bandwidth in one-tenth the space
- Rapidly declining unit costs, in contract to increasing copper cable cost

Table 3-6. Comparison of Photodetectors

| | PIN | APD |
|---|---|---|
| Sensitivity | Low | High |
| Quantum efficiency | ~80% | ~90% |
| Response | Fast-sub ns | Slow ~ ns |
| Noise | Shot-noise limited | Excess noise (factor 5) due to multiplication |
| Gain | 0 dB | 10 ~ 20 dB, optimal gain for noise and bandwidth |
| Remarks | | Temperature compensation for stabilized gain |

- Extremely low-loss; a few tenths of a dB per kilometer, with low dispersion, virtually eliminating repeaters
- Freedom from electric interference
- Greater security.

Although fiber optics has been developed to a state where many experimental systems have been fielded over the world, only a few systems actually carry commercial traffic. Further research and development efforts are essential.

- Realization of low-loss cable, connectors and splices
- Improvment of reliability of optical sources, both in 0.8 to 0.9 and 1 to 1.7 μm
- Development of efficient sources and photodiodes in the 1.3 to 1.5 μm wavelength region
- Stabilization of laser modes under operational conditions
- Development of high bit rate modulation.

High performance optical fiber prices have dropped by as 10:1 factor over the 1975 - 1980 span, as production transitioned from laboratories to pilot plants. With increased efficiency of high volume production, price will drop by another order of magnitude of 2000. Regarding solid state light sources, there has been rapid advancement over the last few years in areas such as increased lifetime, power output, linearity, radiation pattern, and efficiency. These improvements will likely continue over the next few decades.

In the interest of the current study, a prediction of fiber optic communications system capability has been made and shown in Table 3-7 for the period of the 1990s Because of the dynamic growth and development of the optical field, reassessing the prediction may be needed at two to three year intervals.

Table 3-7. Predicted Optical Fiber Communicatioins System Capabilities

| | Bit Rate (Mbps) | Repeater Spacing (km) | Circuit Length (km) | Fiber | Source | Detector |
|---|---|---|---|---|---|---|
| Large capacity, long haul system | 1.2 ~ 1.6 | 15 ~ 30 | 2,500 ~ 4,000 | Single mode | LD | APD |
| Medium capacity, short haul system | 30 - 400 | 20 ~ 40 | 200 ~ 300 | Single mode or multimode, graded index | LD or LED | APD |
| Small capacity, local system | 10 - 30 | 50 | 10 50 | Multimode, step index or graded index | LD or LED | APD or PIN |

3.6 Packet Radio. Packet radio is a technology that extends application of packet switching, as evolved for networks of point-to-point communication landlines, to the domain of radio This technology offers a highly efficient way of utilizing a multiple-access radio channel with a potentially large number of fixed and mobile subscribers to support communications and to provide distribution of information over a wide geographic area.

During the early 1970s the ALOHA project at the University of Hawaii demonstrated feasibility of using packet broadcasing in a single-hop system. The successful Hawaii network led to development of multihop, multiple-access Packet Radio Network (PRNET) under the sponsorship of the Advanced Research Project Agency (ARPA). Packet transmission technology can also be applied to satellite channels. There are two packet satellite experiment efforts, one is the Atlantic Packet Satellite Experiment and the other is the Wideband Experimental Integrated Switched Network. General discussion on packet radio technology and description of experiments mentioned above arae given in Section A.8, Packet Radio of Appendix A, Transmission Media of Final Phase 1A Report.

3.6.1 Packet Radio Experiment. All users in a packet-radio network are assumed to share a common radio channel, access to which needs to be controlled to minimize conflict or overlapping transmission. A variety of theoretical and experimental studies have been carried out to determine the most effective techniques for showing a multiple access (MA) channel. The most common techniques are classic ALOHA, slotted ALOHA, and carrier sense. The simplest technique is classic ALOHA which was designed for very-low-duty-cycle application without any access-control capability. Each user transmit its own message independently, however, an overlapping or conflicting packet is recognized, the unsuccessful transmission will be randomly rescheduled at a later time. This scheme is normally implemented using a positive acknowledgment and time-out procedure. The throughput of a classical ALOHA system increases with the channel traffic to a maximum value of 0.189 which is known as the capacity of a classic ALOHA and occurs for a value of channel traffic of 0.5. If the channel traffic is increased beyond value of 0.5, the throughput of the channel will decrease due to occurrence of conflicts.

The slotted ALOHA is a time-slotted version of random access In this process, a central clock establishes a time base for a sequence of slots of the same duration as the packets. A user transmits his packet randomly but synchronizes the start of his transmission with the start of a slot. Therefore, if the packets conflicts they will overlap completely, rather than partially. Conflicting packets will be transmitted by each user by waiting a number of slots which will be chosen by each user randomly and independently. The maximum utilization a slotted ALOHA channel is 36.8 percent which doubles that of a classic ALOHA.

One of the more efficient access-control techniques for a packet radio system is the carrier sense multiple access (CSMA) wherein each user first senses the multiple-access channel or a control channel and then transmits a packet only if the channel is idle. If the channels is determined to be in use, the transmission is rescheduled at a later time according to certain rules adopted by various systems. Various elaborations on the CSMS scheme offer the possibility of achieving 70 - 90 percent utilization of the channel with low end-to-end transmission delay per packet.

Propagational characteristics of the radio frequency band have a major impact on the packet radio design, rendering it desirable for practical packet radio systems to use frequencies in the upper VHF band, in the UHF band and in the lower portion of SHF band. VHF and UHF bands are already heavily allocated and use of spread-spectrum techniques potentially could allow coexistence of a packet-radio system with existing users of the same frequency bands. However, this is a relatively new concept from the regulatory point, and significant technical issues would have to be solved to establish feasibility of coexistence.

A packet radio system consists of three primary network elements of terminals, control stations and repeaters. A terminal contains the RF and digital processing circuits. Necessary terminal capabilities incude the following functions:

- Packet reception, with ability to check the header and text portion and to route the arriving packet to its destination or local user
- Packet retransmission, when acknowledgements are not received in a certain time out
- Efficient routing control betwen terminal and the control station.

The control station demodulates the incoming packets, stores and switches the information, and remodulates the packets onto a broadcasting channel. In addition, it has capability to implement network protocols including initialization, routing, flow control, directory, and accounting functions, and it also serves as an interface to other networks. All the above functions are performed by an on-board microcomputer.

In the event that some of the terminals are too far away from the control station, radio repeaters are used as relay devices which provide network area coverage by extending the range between terminals and stations. A repeater can operate on a single frequency for transmitting and receiving, switching off its receiver momentarily while it transmits a package. Some packages will be lost when this happens, and as in the case of a collision will have to be retransmitted. However, operating at a single frequency saves the expense of frequency-translation equipment. The repeaters use a single frequency for relaying packages to the control location and a different frequency for relaying packets back to the terminals. If two frequencies are used in this way the repeater antennas pointing towards the central station can be highly directional.

For a highly flexible and/or survivable network, each terminal should be within radio range of two or more repeaters, so that this increased network interconnectivity would improve flexibility and survivability. Controlled routing procedures permit use of preferred routes to minimize dellay and prevent propgation of duplicate messages. However, in the event of repeater failure automatic alternate routing procedures will be implemented.

In 1973, ARPA initiated a theoretical and experimental packet radio program. The primary objective is to develop a geographically distributed network consisting of an array of packet radios managed by one or more minicomputer-based stations and to experimentally evaluate the performance of those stations. The testbed is located in the San Francisco Bay Area and it consisted of about 50 fixed and mobile radios distributed north to south from Grizzly Peak, Berkeley to Eichler, Palo Alto and east to west from Mission Ridge, San Jose to Mountain San Bruno. The initial radio equipment designed was the Experipmental Packet Radio (EPR) and a new development completed in 1978 was designated Upgraded Packet Radio (UPR). A selected 20 MHz bandwidth and 140 MHz bandwidth in the 1710 - 1850 MHz is employed by EPR and UPR, respectively. Two transmission rates of 100 and 400 kbps are available for EPR corresponding to spread-spectrum pattern of 128 and 32 chips per bit. The data rate of UPR is approximately the same but higher chips per bit rate is used to enhance electronic counter-countermeasure capability.

3.6.2 Packet Satellite Experments. There are two packet satellite experiments. The firrst one is the Atlantic Packet Satellite Experiment which has been completed recently. The second is the Wideband Experimental Integrated Switched Network of which the experiment plan is currently being developed.

The Atlantic Packet Satellite Experiment was jointly sponsored by the Defense Advanced Research Project Agency, the British Post Office (BPO), and the Norwegian Telecommunications Authority (NTA), with participation of the Defense Communications Agency (DCA) and the USAF Space and Missile System Organization (SAMSO). The satellite network (SATNET) consisted of four INTELSAT standard earth stations located at Efam, WV, and Clarksburg, MS, USA; Goonhilly Downs, England; and Tanum, Sweden. A 38 kHz channel was shared among the earth stations in accordance with demand-assignment multiple-access technique, and this channel is one of the 800 frequency-division multiplexed channels on the global SPADE transponder of the Atlantic INTELSAT IV-A satellite. This full period assigned channel is operated at nominal power levels, supporting 65 kbps data transmission with a bit error probability on the order of $10^{-6}$ and $10^{-7}$. This experiment has been completed and the data is being analyzed.

The other packet satellite experiment is the Wideband Experimental Integrated Switched Network (EISN) which is currently being developed under joint sponsorship of the Defense Communications Agency and the Defense Advanced Research Projects Agency. The network provides a unique experimental capability for investigation of systems issues involved in a communications facility which includes satellite and terrestrial network and which carries large volumes of voice and data traffic. Areas for investigation include the following:

- Demand-assignment strategies for efficient broadcast satellite communications
- Packet voice communication in a wideband multi-user environment
- Alternate integrated switching techniques for voice and data
- Rate-adaptive communication techniques to comply with varying network conditions
- Routing of voice and data traffic
- Digital voice conferencing
- Internetting between satellite and terrestrial subnetworks.

The planned satellite net includes four earth stations at Defense Communications Engineering Center (DCEC), Reston, VA; ISI, Marina del Rey, CA, Lincoln Laboratory, Lexington, MA; and SRI International, Palo Also, CA. The DCEC is a site of both a satellite and a terrestrial node as well as of a gateway interconnecting the two. Locations of the other terrestrial nodes are unspecified.

Among many features of EISN, the following two are of interest to the DSC III study. The first is the transmission of combined data and digital voice in a wide satellite channel with a variable boundary between these two kinds of traffics. The second is the use of various digital rates of voice transmissionn; the higher rates are used for periods of less traffic and the lower rates of periods of heavier traffic.

3.7 Airborne Relay Platform - Aircraft. Using either manned or unmanned aircraft as an airborne relay platform was considered. Several different kinds of manned and unmanned aircraft were examined. The investigation results are documented in Section A.13, Manned and Unmanned Aircraft of Appendix A, Transmission Media of Final Phase 1A Report.

One aircraft which is suitable for airborne relay use with just about the right payload, space and power supply, has been identified. The identified aircraft is E-system L-450, which is a multi-mission, single-engine, high-altitude, long-endurance aircraft. This aircraft can be operated as either a manned aircraft or a remotely piloted vehicle (RPV). L-450F is the designation for the RPV version, and the military designation is XQM 93A.

The aircraft can fly slowly in circles at altitudes between 13.7 to 168 km (45,000 to 55,000 feet) for 24 hours. The L-450 payload capacity is 26 cubic feet. About 20 cubic feet is available as one continuous bay aft of the cockpit, and an additional 6 cubic feet is available in a narrow area off the primary 20 cubic foot payload bay. For L-450F, the RPV version, the cockpit provides another 18 cubit feet for payload. The total payload space is 44 cubic feet, and the total payload capacity is 1100 pounds. Electric power available is 6 kW at 28 volts.

The L-450 is powered by a PT-6A turboprp engine manufactured by United Aircraft of Canada, Ltd. This engine now has over 10 million flying hours, and it has been installed in 2,000 operational aircraft. The engine experienced an in-flight shutdown rate of 1 per 100,000 hours operating time. The time between overhaul is up to 7,000 hours.

The major parameters given by E-system specification are listed in Table 3-8.

3.8 <u>Airborne Relay Platform</u>. A tethered balloon can be used as an airborne relay platform. Comparing with aircraft or other relay platforms, the drawback of a tethered balloon is the limited altitude which in turn limits the line-of-sight range. Some technical aspects of tethered balloons have been discussed in Section A.15, Tethered Balloon Characteristics and Capability of Appendix A or Final Phase 1A Report. The following paragraphs provide essential information for the tethered balloon system recommended for use in Germany.

Table 3-8. L-450F Specification

| Description | Specification |
|---|---|
| Endurance | Over 24 hours |
| Service ceiling | Over 25,000 feet |
| Stall speed | 61 knots |
| True airspeed (maximum endurance) | 200 knots |
| Maximum rate of climb | 3,000 feet per minute |
| Time to 40,000 feet minimum | 21 minutes |
| Takeoff distance | 1,200 feet |
| Gross weight (manned) | 4,600 pounds |
| Gross weight (unmanned) | 5,300 pounds |
| Maximum payload | 44 cubic feet |
| Turboprop engine | PT-6A |
| Available electric power | 6 kW, 26 volts |

The aerostat consists of the balloon, tether cable, winch, power for wind, and a ground-based mooring structure and controls. Currently, Sheldahl, Advanced Products Division in Northfield, Minnesota, is manufacturing two of the largest state-of-the-art tethered balloons for use as a stale airborne platform. These have nominal volumes of 250,000 cubic feet and 365,000 cubic feet, known as the CBV250A and CBV365A, respectively. The configuration of the mooring and servicing machinery is similar for both sizes.

3.8.1 Balloon. The hull and stabilizing fins of these helium-fitted balloons are made of laminates of plastic films and fabric. Their appearance is similar to the commercially deployed blimps used for advertising purposes.

Buoyant forces vary as a function of wind speed and radiation effects on helium temperature. These two parameters can be predicted only within broad limits. For this reason an operational constraint is that the weight of the tether cable should not exceed that which can be safely supported by buoyancy alone in the absence of wind.

High winds and lightning are the principal hazards to survival. Hull, fins and rigging of aerostats have never been damaged while internal pressure was maintained. Failure of the pressure control system, by malfunction or lightning damage reduces the structural and aerodynamic efficiency to a point where even a moderate wind gust may cause the tether to break.

The CBV 250A, with nominal volume of 250,000 cubic feet, a length of 175 feet, a diameter of 56.8 feet, and a tail span of 82 feet can carry about 4,000 pounds of equipment to 10,000 feet (including on-board power supply and pressure control equipment) and is designed to operate safely in 70 knot winds at altitude. The CBV 365A is a "stretched" version of the CBV 250A, with an overall length of 220 feet (about that of a Boeing 747) and a load carrying capacity of approximately 8,000 pounds at 10,000 feet or 3,700 pounds at 15,000 feet.

Each aerostat is equipped with an air-inflated fairing to enclose antenna arrays, electronic equipment and other payload components vulnerable to environmental exposure. During flight the aerostat is connected to a ground mooring system by a steel tether cable which incorporates a power cable when power is supplied from the ground.

3.8.2 Mooring and Servicing System. The ground-based mooring system consists of a central machinery enclosure and a tower mounted on a large bearing, a horizontal boom which can be rotationally driven, and a circular rail, supporting the boom end. When moored, the nose of the aerostat is secured to the top of the tower.

A single operator can maintain the aerostat on station and a crew of 4 to 6 persons can launch and recover it. The boom, rail and center bearing permit the system to be rotated either by wind forces on the aerostat and cable or by internal power to minimze aerodynamic loading.

3.8.3 Airborne Power Supply. The power supply can be provided by either on-board systems such as Wankel engine-alternator arrangement or from the ground by means of the tether cable. The power requirements for ground supplied power for eitehr the CBV 250A or CBV 365A are in the same order of magnitude. The CBV 250A requires about 2.5 kilowatts when on station and about 5 kilowatts during retrieval operations, and the CBV 365A requires 2.5 kilowatts on station and about 6 kilowatts during retrieval. The main load is needed for the blowers during the one to two hours retrieval period.

When supplying power from the ground, the 60 Hz supply is converted to 400 Hz and transformed to 3,000 volts for transmission over th tether cable. At the aerostat it is transformed back to standard voltages. The use of 400 Hz reduces substantially the weight of the required transformers.

3.8.4 Telemetry and Command System. The telemetry and command system continuously monitors such aerostat data as altitude, windspeed, hull, fin and windscreen pressure, helium and ambient air temperatures, blower, valve and power system conditions; and vehicle pitch, roll and heading.

The system consists of a control section, housed in a console at the ground control station and an aerostat control unit carried aloft by the aerostat. Figure 3-2 shows a powered tethered balloon system.

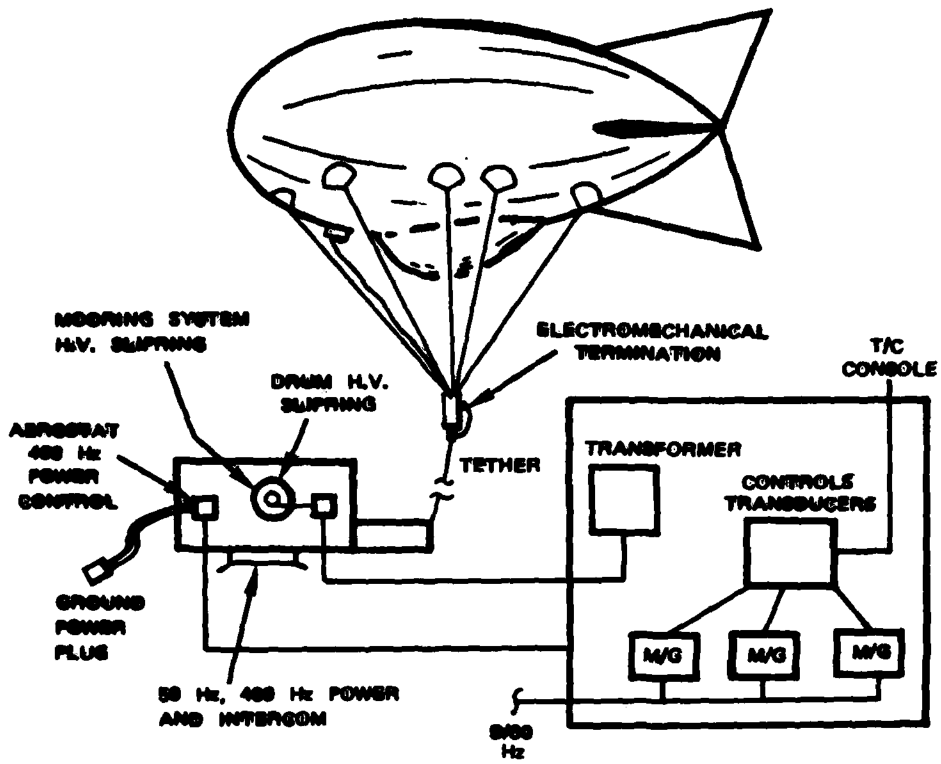



Figure 3-2. Tethered Balloon System

## 4.0 REGULATORY BARRIERS AND REGIONAL CHARACTERIZATION

This section provides a synopsis of international, regional, and national regulatory barriers that are applicable to radio communications practice, as well as a summary of the topographic and climatic features that characterize the various important areas of interest. These regulations and environmental factors affect not only influence selection of transmission media and frequencies to be used, but in turn also impact the alternative system designs proposed for areas of interest.

### 4.1 Regulatory Barriers

Major international, regional, and national regulatory barriers are summarized in following Subsections 4.1.1 through 4.4.4. Additional details are elaborated in Appendix B to this report.

4.1.1 Introduction. In principle, any country is free to establish national defense communications capability as required for the safety of that country. In practice, environmental constraints related to mutual interference subject national-defense radiocommunications activities to all applicable regional and international regulations in force as well as to the same legislation that governs operation of civilian systems.

The major constraint of the various regulations is frequency management, which is the topic of this discussion. The international agencies, particularly the International Telecommunication Union (ITU), the International Telegraph and Telephone Consultative Committee (CCITT) and the International Radio Consultative Committee (CCIR), issue recommendations and reports which are not binding, and which will not be addressed here in depth due to their level of details and the numerous volumes comprising those documents. However, if the planned DCS III will interface with facilities of other countries these recommendations will be important because most countries have adopted some of them and others are in the process of doing so.

Both the international and national radio regulations (RR) basically address frequency allocation, which allocate frequency bands by types of services, and establish procedures for registration of frequencies to enable recording of frequencies in use, planning by future users, and granting of relative priority over future users.

4.1.2 International Regulatory Barriers. Significant constraints on radiocommunications imposed by the ITU Radio Regulation are identified in following Subsections 4.1.2.1 and 4.1.2.2. The groups of countries that are affected by these constraints are summarized in the notes presented in Table 4-1.

The relationship between national and international regulations for most countries is generally characterized by the following:

- Authority for operating in any country controlled only by national regulations
- National regulations in compliance with ITU international regulations but may be more restrictive
- Minimum bounds of national regulation constraints defined by international regulations
- Class G3E - Radiotelephone PM prohibited
- Class A3E - Radiotelephone double sideband discouraged
- International registration required
- Frequency assignment coordinated by International Frequency Registration Board (IFFRR)
- Congestion of the spectrum.

4.1.2.1 Terrestrial Communications Systems. A terrestrial communications system is defined as any system which does not involve use of a space station or other object in space. Major constraints on a terrestrial system are listed in accordance with frequency used.

Table 4-1. Summary of Countries Subject to Constraints

| Item | Affected Countries |
|---|---|
| Note 1: | Federal Republic of Germany, Austria, Bulgaria, Cameroon, Guinea, Hungary, Indonesia, Libya, Mali, Mongolia, Nigeria, Poland, the German Democratic Republic, Romania, Senegal, Czechoslovakia and the U.S.S.R. |
| Note 2: | Afghanistan, Saudi Arabia, Bahrain, Bangladesh, Cameroon, Central African Republic, China, Congo, Korea (Republic of), Egypt, the United Arab Emirates Gabon, Guinea, India, Indonesia, Iran, Iraq, Israel, Japan, Jordan, Kuwait, Lebanon, Libya, Madagascar, Malaysia, Malawi, Malta, Niger, Nigeria, Pakistan, the Philippines, Qatar, Syria, Singapore, Sri Lanka, Tanzania, Chad, Thailand and Yemen (P.D.R.). |
| Note 3: | Federal Republic of Germany. |
| Note 4: | Austria, Bulgaria, Hungary, Poland, the German Democratic Republic, Czechoslovakia, and the U.S.S.R. |
| Note 5: | Afghanistan, Algeria, Angola, Saudi Arabia, Australia, Bahrain, Bangladesh, Botswana, Cameroon, Chana, Korea (Republic of), Egypt, the United Arab Emirates, Gabon, Guatemala, Guinea, India, Indonesia, Iran, Iraq, Israel, Japan, Kenya, Kuwait, Lesotho, Lebanon, Malaysia, Malawi, Mali, Malta, Morocco, Mauritania, Niger, Pakistan, the Philippines, Qatar, Syria, Senegal, Singapore, Somalia, Sudan, Sri Lanka, Swaziland, Tanzania, Chad, Thailand and Yemen (P.D.R.). |
| Note 6: | Japan, Pakistan, the United Kingdom, Thailand, the Federal Republic of Germany, Austria, Belgium, Denmark, Spain, Finland, France, Greece, Ireland, Iceland, Italy, Jordan, Libya, Liechtenstein, Luxembourg, Norway, the Netherlands, Portugal, the United Kingdom, Sweden, Switzerland, Turkey and Yugoslavia. |
| Note 7: | Bulgaria, Cuba, Hungary, Mongolia, Poland, the German Democratic Republic, Czechoslovakia and the U.S.S.R. |
| Note 8: | Algeria, Angola, Saudi Arabia, Bahrain, Cameroon, Central African Republic, Congo, Ivory Coast, Egypt, the United Arab Emirates, Ethiopia, Gabon, Ghana, Guinea, Iraq, Israel, Jordan, Kenya, Kuwait, Lebanon, Libya, Madagascar, Mali, Morocco, Mongolia, Niger, Nigeria, Qatar, Syria, Senegal, Somalia, Sudan, Chad, Togom, Yemen (P.D.R.) and Zaire. |
| Note 9: | Australia, Spain and United States. |

Table 4-1. Summary of Countries Subject to Constraints (Concluded)

| Item | Affected Countries |
| --- | --- |
| Note 10: | Afghanistan, Costa Rica, Cuba, India, Iran, Malaysia, Pakistan, Singapore, Sri Lanka, Thailand, Saudi Arabia, Austria, Bahrain, Bulgaria, Congo, Egypt, the United Arab Emirates, Ethiopia, Guinea, Hungary, Iraq, Israel, Jordan, Kenya, Kuwait, Lebanon, Mauritania, Mongolia, Oman, Poland, Qatar, Syria, the German Democratic Republic, Romania, Somalia, Tanzania, Czechoslovakia, the U.S.S.R., Yemen (P.D.R.) and Yugoslavia. |
| Note 11: | Afghanistan, Saudi Arabia, Bahrain, Bangladesh, Egypt, the United Arab Emirates, Spain, Finland, Gabon, Guinea, Indonesia, Iran, Iraq, Israel, Kenya, Kuwait, Lebanon, Libya, Malaysia, Malawi, Mali, Malta, Morocco, Mauritania, Nepal, Niger, Nigeria, Oman, Pakistan, the Philippines, Qatar, Syria, Senegal, Singapore, Somalia, Sudan, Sri Lanka, Sweden, Tanzania, Thailand, Togo, Tunisia, Yemen (A.R.) and Zaire. |

4.1.2.1.1 Systems Operating Below 28.5 MHz.

a. General Constraints

- Class R3E - Radiotelephone FM: Prohibited
- Coordination of Assignment: Conformance with applicable assignment compatibility rules and with specific procedures for dealing with cases of mutual interferences
- Transmission Characteristics: Limitation of such parameters as effective radiated power, bandwidth, spurious emissions, frequency instability, etc.
- Minimum Requirements: Satisfaction of receiver minimum requirements assuring their compatibility with frequency-management rules.
- Scientific Research: Protection of scientific research activity that utilizes radio waves
- Operational Procedures: Observation of procedures and rules governing traffic, safety and distress operation.

4.1.2.1.2 Systems Operating Above 28.5 MHz

a. General Constraints

- Compliance with ITU Frequency Plan Allocation
- Activation of international coordination when interference range exceeds national borders

b. Constraints on Fixed Services Sharing Frequency Bands with Space Communications

- Restrictions of site and frequency selection
- Equivalent isotropically-radiated power (EIRP) restricted on following bands:
  - 1626.5 to 1645.5 MHz (Note 1)
  - 1646.5 to 1660 MHz (Note 1)
  - 2655 to 2690 MHz (Regions 2 and 3)
  - 5725 to 5755 MHz (Regional 1, Notes 2, 3 and 7)
  - 5850 to 7075 MHz
  - 7900 to 8400 MHz

- 10.7 to 11.7 GHz* (Region 1)
- 12.5 to 12.75 GHz (Notes 4 and 8)
- 12.7 to 12.75 GHz* (Region 2)
- 12.75 to 13.25 GHz
- 14.0 to 14.25 GHz (Note 5)
- 14.25 to 14.3 GHz (Notes 5 and 6)
- 14.3 to 14.4 GHz* (Regions 1 and 3)
- 14.4 to 14.5 GHz
- 14.5 to 14.8 GHz*

- Transmitter power limits applicable to following bands:
  - 17.7-18.1 GHz
  - 27.0-27.5 GHz (Regions 2 and 3)
  - 27.5-29.5 BHz

- Additional EIRP restrictions for maximum radiation of antenna falling within 2° from the geostationary satellite orbit. (Ref. RR Chapt. VIII, Art. 15, 1979 WARC for complete listing of constraints).

c. Constraints on LOS Systems Using Airborne Relay Platforms

- None specifically applicable to LOS systems using relay platforms mounted on aircraft, remotely-piloted vehicle (RPV), tethered balloon, or floating balloon

- In practice, utilization of airborne repeaters may subject the following constraints:
  - Radiation of terrestrial antenna in high angle may restrict this type of operation to bands not shared with satellite services
  - Large area covered by the airborne transmission may result in long and difficult negotiations to obtain licensing as the result either of interference to other services or need for international coordination when the interference range exceeds national boarders
  - Implementation of airborne systems may require coordination with national agencies responsible for air navigation safety.

*Application of limits in frequency band is provisional

d. Constraints on Tropospheric and Ionospheric Scattering

- None specifically applicable to tropospheric and ionospheric scattering

- High power required may constrain use of scattering in certain geographic areas due to spectrum congestion

- In bands shared between fixed and space communication, EIRP limitation for the terrestrial stations may restrict cases where tropospheric scattering is viable.

e. Constraints of frequency allocation on millimetric systems using closely spaced relays

4.1.2.2 <u>Space Communications Systems</u>

a. General Constraints

- Advance publication of information on planned satellite network required not earlier than 5 years and not later than 2 years prior to deployment

- Coordination of data with IFRB and other administrations is required

- On bands shared with Fixed Service, coordination of frequency assignment to the earth station with other countries covered by the interference range (coordination area) of the earth station is required (Ref. RR, Chapt. III, Art. 9, 1979 WARC for details)

b. Constraints on Earth Station operating on Frequency Bands Shared with Fixed Service (Ref. RR, Chapt. VIII, Art. 28 for complete listing of constraints)

- Choice of sites and frequencies restricted

- Coordination with countries falling in the interference range (coordination area) of the earth station required (Ref. RR, Art. 9)

- Minimum earth-station antenna angle of elevation limited.

- Off-axis power limited (Ref RR, Art. 23)

- Earth-station EIRP limited

- Above constraints applicable to following frequency bands:
  - 5670 to 5725 MHz (Note 7)
  - 5725 to 5755 MHz (Region 1, Notes 2 and 7)
  - 5755 to 5850 MHz (Region 1, Notes 2, 3, and 7)
  - 5850 to 7057 MHz
  - 7900 to 8400 MHz
  - 10.7 to 11.7 GHz (Region 1)
  - 12.5 to 12.75 GHz (Region 2, Note 8)
  - 12.7 to 12.75 GHz (Region 2)
  - 12.75 to 13.25 GHz
  - 14.0 to 14.25 GHz (Note 5)
  - 14.25 to 14.3 GHz (Notes 5 and 6)
  - 14.3 to 14.4 GHz (Regions 1 and 3)
  - 14.4 to 14.8 GHz
  - 17.7 to 18.1 GHz
  - 27.0 to 27.5 GHz (Regions 2 and 3)
  - 27.5 to 29.5 GHz
  - 31.0 to 31.3 GHz (Note 7)
  - 34.2 to 35.2 GHz (Notes 7 and 9)

c. Constraints on Space Station operating on Frequency Bands Shared with Fixed Service (Ref. RR, Chapt. VIII, Art. 26 and 27 for complete listing of constraints)

- Satisfaction of minimum requirements for space-station position stability
- Maintenance of antenna pointing accuracy (geostationary satellites)
- Maintenance of power flux density at earth's surface, if limited
- Power-flux density constraints applicable to following frequency bands:
  - 1525 to 1530 MHz (Regions 1 and 3)
  - 1530 to 1535 MHz (Regions 1 and 3 up to 1 Jan 1990)
  - 1670 to 1690 MHz
  - 1690 to 1700 MHz (Note 10)

- 1700 to 1710 MHz
- 2290 to 2300 MHz
- 2500 to 2690 MHz
- 3400 to 4200 MHz
- 4500 to 4800 MHz
- 5670 to 5725 MHz (Notes 2 and 7)
- 7250 to 7750 MHz
- 8025 to 8500 MHz
- 10.7 to 11.7 GHz
- 12.2 to 12.5 GHz (Region 3)
- 12.50 to 12.75 GHz (Region 3, and in Region 1, Notes 4 and 8)
- 17.7 to 19.7 GHz
- 31.0 to 31.3 GHz
- 34.2 to 35.2 GHz (for space-to-earth transmissions of territory of countries cited in Note 11)
- 37.5 to 40.5 GHz

4.1.3 Regional Regulatory Barriers. EUROCOM, formed by the European countries belonging to NATO, is intended to standardize operational characteristics of equipment manufactured in Europe, thus making such equipment compatible when the military forces of NATO operate under a unified command system. The one major regional regulatory barrier which may impact the DCS III alternative transmission system design is the EUROCOM D/1 standard, which is concerned only with trunk communication systems for combat zones. The multi-channel trunk links between EUROCOM trunk networks of different nations are known as "gateways," and multi-channel connections between EUROCOM equipment of one nation and a EUROCOM network of another nationa are known as "international access links."

The EUROCOM Hypothetical Reference Circuit (HPR) that has been defined specifies various important system parameters including trunk bit rate, frame structure, synchronization, and multiplexing method, and major parameters of gateway stations and access links also have been agreed upon. Applicable information is documented in Appendix B to this report.

Frequency bands specified for radio relay use are slightly different for some of the NATO countries. These bands in MHz are as follows:

| | | |
|---|---|---|
| • | Belgium: | 225-400, 610-960, 1350-2700 |
| • | France: | 160-400, 400-960, 1350-2700, 4400-5000 |
| • | Germany: | 225-400, 610-960, 1400-1660, 4400-5000 |
| • | Italy: | 225-400, 610-960, 1350-1850, 4400-5000 |
| • | Netherlands: | 225-400, 610-960, 1350-1850, 4400-5000 |
| • | United Kingdom: | 225-400, 610-960, 1350-1850, 4400-5000 |

Ranges of frequencies in other bands are under study. The RF frequency shall be able set at multiples of:

- 0.125 MHz in 225-400 MHz band
- 0.125 MHz (or 0.250 MHz, as secondary choice) in 610-960 MHz band
- 0.250 MHz in 1350-1850 MHz band
- 0.500 MHz in 4400-5000 MHz band.

4.1.4 <u>National Regulatory Barriers</u>. Constraints applicable to Germany and Turkey cited in Subsections 4.1.4.1 and 4.1.4.2 below are limited to requirements additional to those imposed by the ITU RR.

4.1.4.1 <u>German Regulatory Barriers</u>. In the German Federal Republic, overall authority for telecommunications is vested in the Federal Minister for Post and Telecommunications (Bundesminister fur Post und Fernmeldewesen). This authority is derived from the 1977 Telecommunication Equipment Law (Fernmeldeanlagengesetz), which also assigned administrative responsibility for telecommunications to the Deutsche Bundespost (DBP). The Postal Administration Law (Posverwaltungsgesetz) subsequently specified responsibilities of the Federal Minister for Post and Telecommunications with greater precision.

The DBP, a monopoly, sets up and operates telecommunications installations, and grants licenses. The Central Telecommunications Office (Fermeldetechnisches Zentralamt (FTZ) is in fact the executive body governing telecommunications and is the point of contact for subscribers.

Under terms of the Status of Armed Forces Agreements, U.S. forces stationed in Germany hold authority to establish communications networks in specific bands, particularly in the 7.25- to 8.4-GHz band. As part of NATO, U.S. forces many receive authority through ARFA to establish a communications network ~~if~~ that network is considered to be a NATO infrastructure. Otherwise an authorization for installing or operating a network must comply with rules and regulations of the Bundespost and the FTZ. Various sources agree that the Bundespost/FTZ is a difficult barrier against implementation of a communications network in Germany unless the network is established through facilities rented from the Bundespost and uses German equipment.

Although official contact between U.S. forces and the German government is through German military forces, the Bundespost ordinarily becomes involved and has the last word. It can be speculated that a radio system with equipment installed inside of U.S. military compounds may have a better chance of being authorized by the Bundespost than a physical system requiring installation outside of U.S. compounds. However, the Bundespost actually has been reducing the number of RF channels that could be used. Also, use of balloons or RPVs probably would encounter difficulty due to an extended interference range.

For new systems in Germany it is advisable to use radio communications operating in frequency bands already allocated to the U.S. forces by the Status of Armed Forces Agreement and through NATO agreements. For example, installation of cables, wires, or poles outside of U.S. compounds may raise strong objections from the Bundespost, which would require resolution by negotiations at a high governmental level. Other aspects of German national regulation such as equipment approval, available services, etc. are discussed in Appendix B to this report.

4.1.4.2 Turkish Regulatory Barriers. Unlike Germany, Turkey does not have a well-established system for implementing frequency management and other regulatory responsibilities. Frequency assignment is under control of the Turkish General Staff (TGS), the General Directorate of PTT is responsible for regulating the civil use of telecommunication, and Turkish radio frequency management is in accordance with ITU Radio Regulations.

In Turkey the national microwave system is not large, and installation of systems for U.S. forces is controlled by the Turkish General Staff. Thus the only constraints are of a political nature, and once an agreement is reached between the United States and Turkish governments no serious limitations are expected in selection of communications systems. However, due to a high rate of vandalism in the country it is not advisable to select a communications system requiring installation of cables, wires, or poles outside secured areas.

## 4.2 Regional Characterization

Subsection 4.2.1 through 4.2.3 provide a summarized charecterization of the topographic and climatic conditions prevailing in the the three areas of interest of Hawaii, Germany, and Turkey. This and other pertinent related information is elaborated in greater detail in Appendix C to this report.

4.2.1 Hawaii. The summarized topographic characterization and climatic conditions of the Hawaiian Islands presented in this section is limited to discussion of the DCS communications requirement on Oahu Island.

4.2.1.1 Topographic Characterization. The Hawaiian Islands consisting of 124 small islets and 8 major islands, are located approximately 3,540 km southwest of San Francisco and one-third of the way from San Francisco to Australia. Because no other land lies between Hawaii and the United States mainland. The Hawaiian Islands are in a strategic position on both shipping routes and trans-Pacific air routes between the Americas and Asian countries.

All of the islands actually are the peaks of a chain of mountains which were built by volcanoes. Some volcanic activity still exists in a few peaks but is not very extensive. From west to east the major islands are Niihau, Kauai, Oahu, Molokai, Lanai, Kahoolawe, Maui, and Hawaii.

The chain of small islands, rocks, shoals, and coral atolls that extends for about 2,000 km approximately northwest of the major islands is uninhabited with the exception of military installations on Kure, Midway, and French Frigate Shoal.

Population is over three-quarters of a million persons. The capital city, Honolulu, on Oahu is the center of metropolitan area which has over 80 percent of the Hawaiian Islands' population.

The Hawaiian Islands may be characterized as having some coasts which are low and sandy, and some bold cliffs that rise abruptly from the ocean.

Oahu Island is the most important in many ways, particularly for military purposes. The two important land elevations are the Koolau Range, which parallels the entire northeastern coast at average elevation of 610 meters and whose highest peak is 946 meters and the Waianae Range, which parallels the western coast at a somewhat higher elevation and whose highest peak is 1228 meters. Both ranges are eroded with deep ravines and gorges and are indented with bays. Few lakes and rivers characterize the surface and streams are chiefly short mountain torrents.

4.2.1.2 Climatic Conditions. The maritime climate of Oahu is unusually pleasant for the tropics, with extremely equable temperature conditions from day-to-day and season-to-season. Persistent trade winds flow from the northeast, and the sunniness of the leeward lowlands is in contrast to the persistent cloudiness over nearby crests. Rainfall has remarkable variation over short distances.

Wind and cloud cover considerably modify the temperature as well as the topography, extremes in temperature tending to occur mostly on leeward coasts or leeward slopes of mountains where the absence of trade winds permits heat or cold to accumulate. The pattern of the trade winds tends to follow the sun, which causes six of the major islands to average 1145 millimeters of rain per year over their entire surface instead of 635 millimeters per year as in the Leeward Islands.

Although temperature on the average decreases with altitude islands tend to absorb heat, leading to creation of inversion layers, with temperature increasing slightly with altitude to about 1.5-2.1 km, above which cool air lies.

4.2.2 Federal Republic of Germany. Following Subsections 4.2.2.1 and 4.2.2.2 briefly summarize topographic characteristics and climatic conditions of the Federal Republic of Germany. The area of interest of this study is a rectangular area within the Federal Republic of Germany that is roughly bounded by Muhl, Wiesbaden, Heidelberg, Karlsruhe, and Zweibrucken. About two dozen DCS Communications nodes are located in this area.

4.2.2.1 Topographic Characterisistics. Strategiacally located in north-central Europe, the Federal Republic of Germany (F.R.G. West Germany) includes about 248,480 square km, or an area about the same size as the state of Wyoming. Politically, it is bounded by Denmark to the north and Switzerland and Austria to the south, bound by the Netherlands, Belgium, Lexembourg, and France to the west, and by East Germany and Czechoslovakia to the east. Internally, the F.R.G. consists of 10 states with West Berlin located 177 km inside of East Germany and entirely surrounded by its territory.

In West Germany there are the two belts of high population density within West Germany lie along or near the Rhine River and the other is in the Borderland. The two meet at the Ruhr, a tributary of the Rhine, which contains the largest concentration of big cities and industries. Outside the Ruhr region the high density areas are usually associated with a large number of towns and medium-sized cities rather than big cities. The principal exceptions are the three great metropolises of Bremen, Hamburg, and West Berlin. The former are both seaports, and West Berlin has a unique political status.

The country is generally flat in the north and hilly in the central and western areas, rising in the southwest to more than 1220 m above sea level in the Black Forest. The northern part of the Rhine valley is about 24 km wide near Darmstadt about 40 km wide at Karlsruhe, the transition taking place near Mannheim. On the east bank of the Rhine, Mannheim is one of the busiest river ports and manufacturing towns in the entire Rhine Rift. The valley is at about 100 meters above sea level, with little variation in elevation throughout.

The region between Darmstadt and Heidelberg contains the western part of the heavily forested Odenwald. Between Heidelberg and Karlsruhe, there are gently rolling hills. The area west of the Rhine Rift is quite hilly and is laced with dense forest which extend in a southwest-to-northeast direction.

4.2.2.2 Climatic Conditions. The Federal Republic of Germany lies entirely in the temperate zone, and westerly winds prevail throughout. Except for the Alpine region on its southern border, the country does not experience extreme climatic differences. However, the climate is subject to quick variations when the warm westerly climate of the Gulf Stream collides with the more extreme climate from northeastern Europe.

The highest average monthly temperature (20$^{o}$C) occurs in the Rhine Main Plain. The Rhine Rift has the best climate in all of Germany, mainly because the spring comes earlier and summers are longer. The prevailing winds move from the south, west, or northwest. The windiest season for the Rhine Rift is early spring.

Surface elevation and relief are the most important determinants of amount of precipitation. The Central Uplands averages a yearly amount of rainfall between 685 and 1,524 millimeters, the Rhine Rift being near the lower limit. The maximum rainfall for this region occurs in summer with July the wettest month. Snow may begin falling in October above 460 meters and about a month later at lower elevations, occuring throughout the country into mid-April and into May at the higher elevations. The least amount of snow occurs in the Rhine area, which may receive rain instead.

4.2.3 Turkey. This report reflects consideration of the various aspects of the DCS Communications requirement. Due to the fact that only about a dozen communications nodes of interest for the present study exist within the vast area of Turkey only a very condensed description of topographic characteristics and climatic conditions is given below.

4.2.3.1 Topographic Characteristics. The Republic of Turkey in the eastern Mediterranean region, occupies a land area of 767,000 square km, which is slightly smaller than Texas and Louisiana combined. The Republic shares common borders with Bulgaria and Greece to the northwest, the USSR and Iran to the east, and Iraq and Syria to the south. Turkey is adjacent to the Black Sea to the north, the Mediterranean Sea to the south, and the Aegean Sea to the west.

Population is more dense along the coastal regions where climate and soil conditions are more favorable to agriculture, as well as in the western half of the country. The most sparsely populated areas are the central highlands and the eastern and southeastern mountain regions. The population totaled 35.7 million in 1970 and is expected to double by 1995.

Istanbul, on the European side of the Bosporus Strait, is the most populated city. The capital city of Ankara in central Turkey has the second largest population in Turkey.

Except for a small segment along the European side, Turkey structually is a very complex region. Over 80 percent of the land surface is rough, broken, and mountainous. The two large mountain formations are the Pontic Mountains along the Black Sea and the Taurus Mountains bounding the Mediterranean Sea. Geographic faulting is still in progress, making Turkey one of the ranking earthquake regions of the world.

4.2.3.2 Climatic Conditions. The climate of Turkey is continental temperate, with some Mediterranean and maritime temperate influences. In the interior plateau there is a wide range of temperature, with winters cold and averaging $1^{\circ}C$ in January and frost likely to occur more than 100 days during the year. Summers are warm, with high daytime temperatures and cool nights. From 254 to 432 millimeters of rainfall are experienced annually on the plateau.

Along the coastal regions winters are mild and summers moderately hot. Along the Black Sea August is the hottest month, with a mean temperature of 22$^{o}$C. Along the Aegean Sea August temperatures often exceed 32$^{o}$C. The western coastal areas do not experience frost, but in the east snow may remain on the ground for as long as four months of the year. Rainfall averages from 508 to 962 millimeters annually along the Aegean and Mediterranean seas to over 2540 millimeters along the Black Sea.

The climate of eastern Turkey is most extreme, with summers hot and extremely dry and winters bitterly cold. Spring and autumn are both subject to sudden hot and cold spells.

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## 5.0 DEVELOPMENT OF DCS III TRANSMISSION SYSTEM ALTERNATIVES

This section presents two alternative transmission designs for the DCS III time frame and for the three areas of interest, Oahu Island of Hawaii, the central region of the German Federal Republic, and Turkey. Baseline system descriptions as defined in Section 2.1 for each area are also included here to facilitate comparative system performance and cost trade-off studies that will be undertaken subsequently.

According to the Statement of Work of this project, system design is to be conducted for the following type classes:

- Densely-netted DCS user region
- Sparsely-netted DCS user region
- Regional DCS interconnection.

Central Germany and Turkey were chosen as representative regions for densely-netted and sparesely-netted DCS user regions respectively. However, later DCEC instructions directed the regional DCS interconnections to be replaced by Oahu Island, and millimeter-wave radio to be included as one of the transmission media used.

### 5.1 Introduction

Initial action to implement the Evaluation of DCS III Transmission Alternatives study consisted of gathering information on the existing and planned DCS trunks in the three areas noted. This material was collected from various concerned organizations such as TRW/DSSG Inc., Page Communications, Inc. Northrop Company files, and the Defense Communications Engineering Center (DCEC). The six major sources of information supplied by DCEC are the following:

- Trunking data of central Germany and Turkey
- Summarized DCS circuit and trunk files for central Germany, Turkey, and Hawaii
- Projected European DCS Connectivity, 1985 (DCA Drawing DCA-COMOCN-003)
- European Defense Communications System (DCA Drawing EUR-COM-CM-005, Sheets 1-5, 1 Jan 1979)

- DCS Multiplex Configuration, European Area (DCA Drawing EUR-COM-CM-007, 1 Jan 1979)
- Digital European Backbone Multiplex Configuration (DCA Drawing DCA-SK-200-129, Sheet 1-8, 27 July 1976).

Item 1 lists 19 and 11 user locations for central Germany and Turkey respectively, and the number of voice channels and their rates are specified. Item 2 lists circuit data for each region, the information for each circuit including end-user locations, circuit type (TTY, voice, data), and numbers of circuits for each type. However, comparison of available information from the listed items indicates that not all information is consistent.

In accordance with the baseline definition given in Section 2.1, the trunking data for Item 6 and for the DCS Five Year Plan are used as a basis for network-requirement analysis and transmission-system design for central Germany and Turkey. The data base for analysis and design of the system for Oahu Island is defined in Section 5.3.1.

## 5.2 Transmission System Alternative Designs

The candidate medium or media and the network designs identified herein for the noted areas of interest represent results of a step-by-step approach developed in support of this effort. Major topics addressed by this study include the following:

- Network trunking requirement analysis
- Topographic and climatic considerations
- Regional characterization considerations
- Frequency-band availability
- Medium or media selection
- Network designs.

Details of significant associated information relating to such matters as international, regional, and national regulatory barriers, topographic and climatic conditions, and local environments for the various areas of interest are elaborated and are presented for convenient reference in Appendices B and C to this report.

The medium or media for a particular region were initially selected on a basis of careful and balanced examination of applicable requirements and environmental factors as well as of consideration of their physical nature, capability, and technical constraints. Network requirements and capability of selected media then permitted a trial network to be defined, which in turn enabled selection and/or computation of transmitter power, antenna type and gain, modulation and detection scheme, link budget margin, and system capacity. Finally, the total network will be modified in accordance with results of analysis.

This report does not reflect consideration of multiplexing equipment and switching schemes because of instructions to that effect received from cognizant authority. It therefore is assumed that the DRAMA multiplexer equipment will be used for DCS III. Also, because only trunking data are used for network design and circuit data and and traffic statistics are not available, switching has not been addressed in this current study.

## 5.3 Candidate Alternative Transmission Systems for Hawaii

This section presents the baseline transmission system for Hawaii together with two proposed alternative designs. Accomplished work reflects placement of primary emphasis on the intra-island communications requirements for Oahu Island.

A partial listing of the DCS Circuit and Trunk Data File of the Hawaiian Islands has been provided by the DCEC, subsequent instructions were issued to consider only the terminals or user locations shown in Figure 5-1 and the number of required T1 equivalent channels between various pairs of users listed in Table 5-1. It should be noted that one T1 channel is assigned for every ten to twenty voice-channel-equivalent circuits and that there consequently exists an approximately 20- to 60-percent growth capability. The wideband data requirements between Hickam and Wahiawa (6.176 Mbps) and between Kunia and Wahiawa (13.687 Mbps) were converted into equivalent T1 channels (1.544 Mbps) and combined with the voice requirement. Although the work addressed in this section is based on the above-mentioned Figure 5-1 and Table 5-1, information contained in the partial listing of the DCS Circuit and Trunk Data File also has been used for reference.

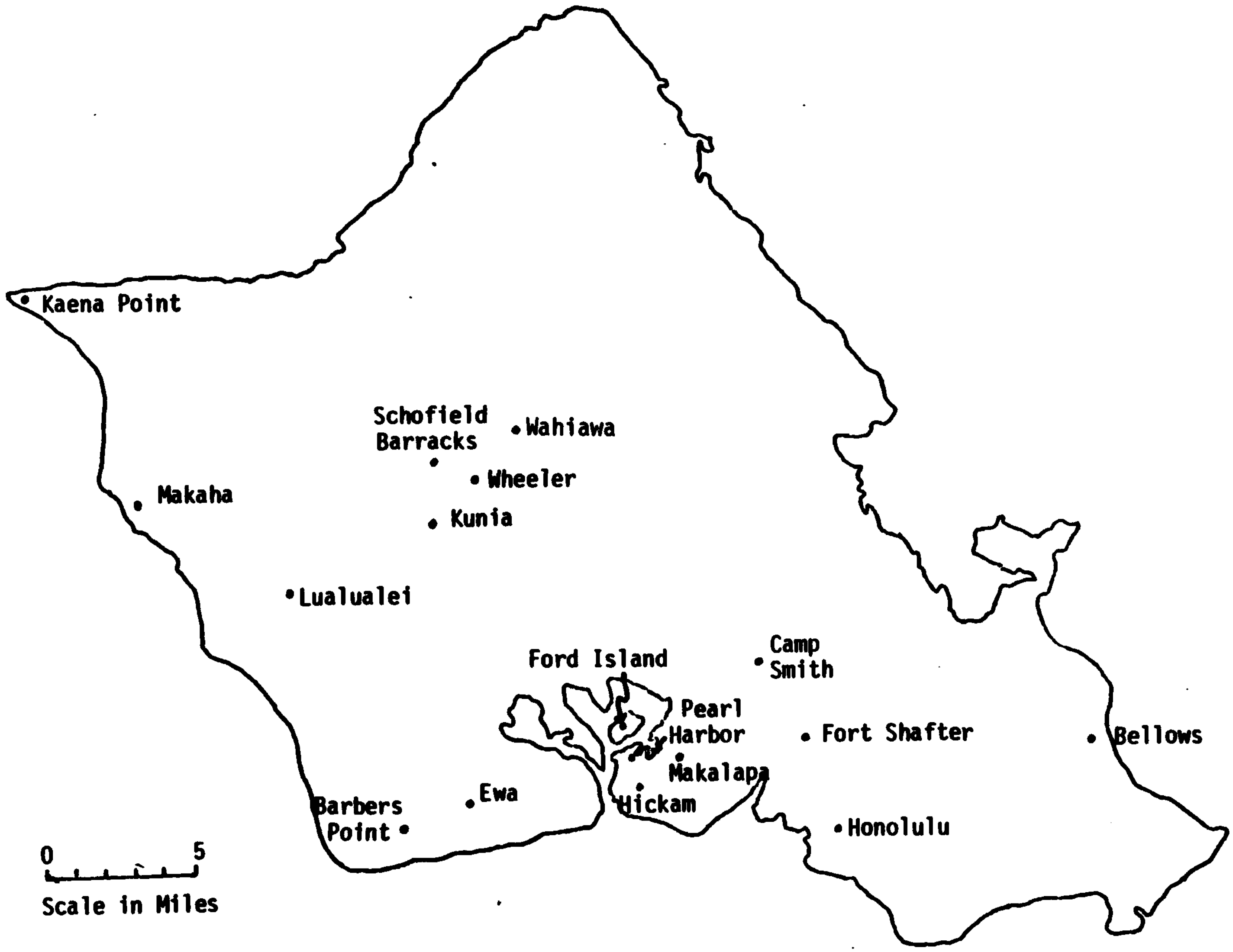


Figure 5-1. DCS Terminal Locations on Oahu Island

Table 5-1. DCS T1 Requirements (Intra-Island)

| Node Location A | Node Location B | Number of T1 Channels |
|---|---|---|
| Barbers Point | Ford Island | 3 |
| Barbers Point | Lualualei | 1 |
| Barbers Point | Wahiawa | 1 |
| Bellows | Hickam | 2 |
| Bellows | Wahiawa | 1 |
| Camp Smith | Hickam | 2 |
| Camp Smith | Makalapa | 2 |
| Camp Smith | Wahiawa | 3 |
| Ewa | Wheeler | 2 (one-way) |
| Ford Island | Wahiawa | 5 |
| Fort Shafter | Pearl Harbor | 1 |
| Fort Shafter | Wahiawa | 2 |
| Hickam | Honolulu | 1 |
| Hickam | Pearl Harbor | 4 |
| Hickam | Wahiaha | 10 |
| Hickam | Wheeler | 1 |
| Kaena Point | Wahiawa | 2 |
| Kunia | Wahiawa | 12 |
| Lualualei | Wahiawa | 2 |
| Makaha | Pearl Harbor | 1 |
| Makalapa | Pear Harbor | 2 |
| Makalapa | Wahiawa | 3 |
| Pearl Harbor | Schofield Barracks | 1 |
| Pearl Harbor | Wahiawa | 7 |
| Schofield Barracks | Wahiawa | 1 |
| Wahiawa | Wheeler | 2 |

5.3.1 Hawaii Baseline System

As an initial step in the DCS III Transmission Alternatives Study, information was gathered for the Hawaiian Islands at Ouahu, Molokai, and Kauai to establish baseline network. However, because certain essential information on the existing and planned DCS was not available, the collection effort was limited to identification of the DCS locations and the T1 trunking requirements between endpoints. Resulting data as given in Tables 5-1 and 5-2 summarized these trunking requirement. The total number of TI channels associated with each node is given in Table 5-3. A system fulfilling these requirements might be planned and built later, either in the form of a government-owned facility or a leased service provided by a common carrier.

Because available information remains inadequate to define a baseline system precisely, a hypothesized microwave LOS relay network is proposed in view of the fact that some microwave LOS system facilities already exist Hawaii. In addition, the DRAMA-type digital radio will be available for implementation.

The Phase IA effort is limited to preliminary design of microwave links because specific details other than items such as LOS paths, repeater stations, and a map survey that may be required for actual planning is beyond the present work scope.

Table 5-2. DCS T1 Requirements (Inter-Island)

| Subscriber Location A | Subscriber Location B | Number of T1 Channels |
|---|---|---|
| Barking Sands | Pearl Harbor | 1 |
| Kokee | Wheeler | 2 |
| Molokai | Wheeler | 3 (one-way) |

Table 5-3. Number of T1 Channels Associated with Oahu Communication Nodes

| Location | Number of T1 Channels |
|---|---|
| Barbers Point | 5 |
| Bellows | 3 |
| Camp Smith | 7 |
| Ewa | 2 |
| Ford Island | 8 |
| Fort Shafter | 3 |
| Hickam | 20 |
| Honollu | 1 |
| Kaena Point | 2 |
| Kunia | 12 |
| Lualualei | 2 |
| Makaha | 1 |
| Makalapa | 7 |
| Pearl harbor | 17 |
| Schofield Barracks | 2 |
| Wahiawa | 51 |
| Wheeler | 10 |

5.3.1.1 Baseline Assumptions. Due to lack of circuit traffic information, allocated resources and time, baseline system definition of Oahu Island is based on the following assumptions:

- A hypothesized microwave LOS radio network will be defined as a baseline system meeting requirements listed in Table 5-1 for locations identified in Figure 5-1
- Inter-island requirements will be disregarded in accordance with DCEC instructions

- Primary routing of the T1 channels for the microwave radio networks will be the most direct routes between two subscriber locations, and only a minimum number of alternate routes for the most essential links will be proposed

- Multiplex equipment will not be considered in the baseline system.

The alternate route provides capability to route traffic among terminal sites within the triangle of Relay A, Relay C, and Wahiawa in both directions in case any one of the three links has been disabled. However, no additional alternate sites have been added, and only the numbers of T1 channels of three links have been increased.

5.3.1.2 Remarks on Hawaii Baseline System. The baseline system under discussion is hypothetical and has no relation to actual or planned DCS capabilities in Hawaii. The baseline will only used as a reference point which may be used to compare alternative transmission media and to demonstrate improvement in performance and/or cost.

5.3.2 Alternative System Design H-1. The communications network design developed in this section is applicable to Hawaii, and to Oahu in particular. The design is based both on government-supplied trunking requirements between users on Oahu and on the requirement that the selected transmission media as well as the network configuration can accommodate 20- to 60-percent future expandability. Due to the overall geographic size of Oahu in comparison to Turkey, survivability in the event of a direct nuclear attack cannot be made a key design constraint for this effort. Thus trunking requirements, expandability, cost, and availability shall be given maximum weight instead.

5.3.2.1 Network Configuration. A communications network is an interconnection of a number of users. Conceptually the simplest system involves interconnection of all users by dedicated links. Such an interconnection for six users is shown in Figure 5-2a, wherein it should be noted that 15 separate links are required to connect all users or nodes. However, by use of a central switching station as diagrammed in Figure 5-2b the number of links connecting the various nodes can be reduced from 15 to 6. If the number of users is large, availability requirements dictate use of multiple star configurations such as the double-star configuration shown in Figure 5-2c. In this case, unlike the single-star network, an outage of one of the central switching stations does not disrupt the total communication network. However, both network configurations will be considered.

Figure 5-3 indicates the T1 traffic requirements between users or nodes located on Oahu as supplied by the government. Except where noted, all traffic is two-way. Figure 5-3 also shows that 13 members of the set are connected not only to each other but also to Wahiawa as well. For example, a two-way communication link exists not only between Lualualei and Barber's Point but also between Lualuale and Wahiawa and Barber's Point and Wahiawa. This suggests the possiblity of deleting the direct link between Lualuale and Barber's Point, with connection between the two being implemented by the routing of traffic and switching at Wahiawa. Table 5-4 summarizes all of the candidate links which can be similarly deleted and Figure 5-4 shows the resultant candidate single-star network for Oahu. In addition, Table 5-4 shows that some of the deleted two-way links such as Wheeler to Hickam, Makala to Pearl Harbor, and Hickam to Bellows involve only one or two T1 links while spanning distances of more than ten miles each. Thus, even with some anticipated growth it is difficult to justify these dedicated links solely from an economic point of view.

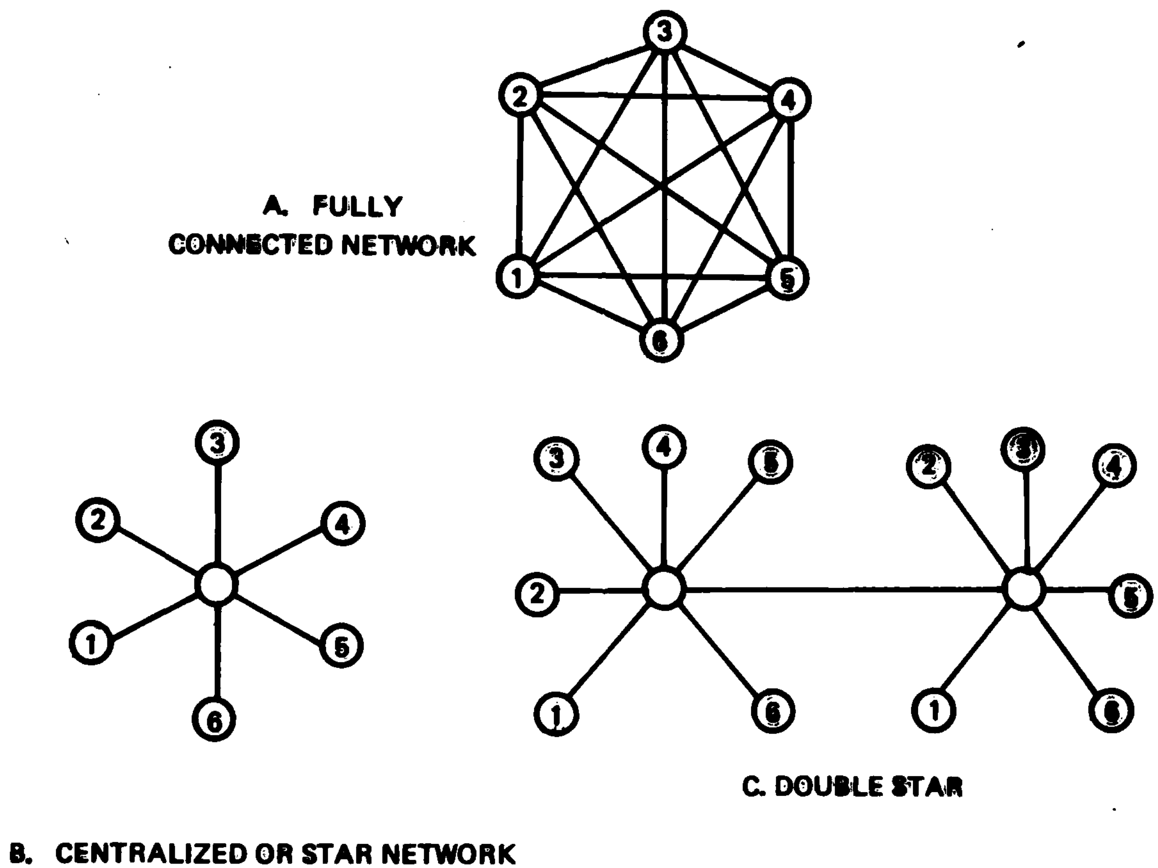


Figure 5-2. Candidate Network Topologies

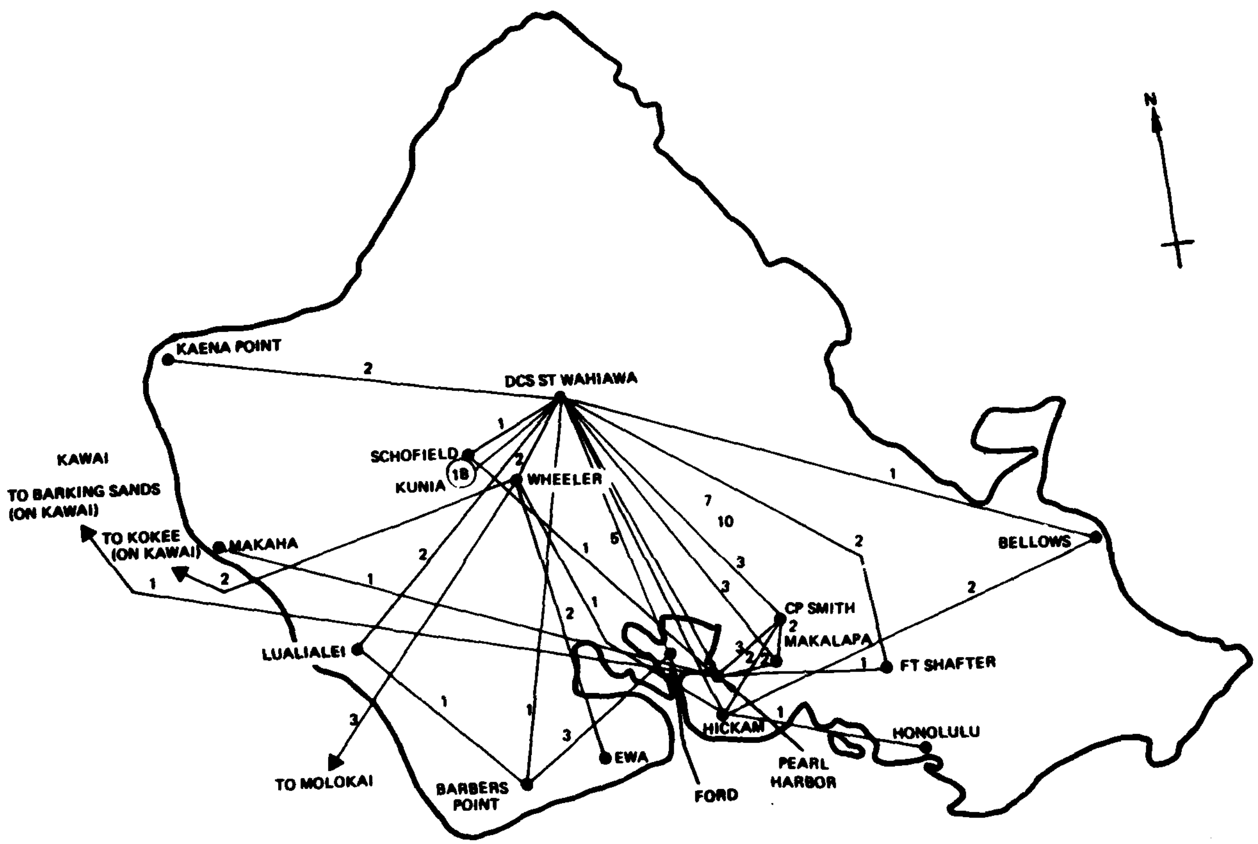


Figure 5-3. TI Channel Requirements Between Users for Oahu

Table 5-4. Candidate List of Deleted Links for Single-Star Oahu Network

| Two-Way Link | Data Rate | Approximate Link Length in Miles |
|---|---|---|
| Wheeler to Hickam | 1T1 | 10.0 |
| Makaha to Pearl Harbor | 1T1 | 16.1 |
| Schofield to Pearl Harbor | 1T1 | 10.5 |
| Lualualei to Berbers Point | 1T1 | 6.9 |
| Berbers Point to Ford Island | 3T1 | 6.1 |
| Pearl Harbor to Camp Smith | 3T1 | 2.7 |
| Hickam to Camp Smith | 2T1 | 3.5 |
| Pearl Harbor to Makalapa | 2T1 | 1.9 |
| Makalapa to Camp Smith | 2T1 | 1.5 |
| Pearl Harbor to Fort Shafter | 1T1 | 5.4 |
| Hickam to Bellows | 2T1 | 13.0 |
| Hickam to Pearl Harbor | 4T1 | 1.2 |
| TOTAL | | 78.6 |

AD-A101 359 TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CA F/G 17/2.1
EVALUATION OF DCS III TRANSMISSION ALTERNATIONS. PHASE 1A REPOR--ETC(U)
MAY 80 T M CHU DCA100-79-C-0044
UNCLASSIFIED TRW-35142 SBIE-AD-E100 436 NL

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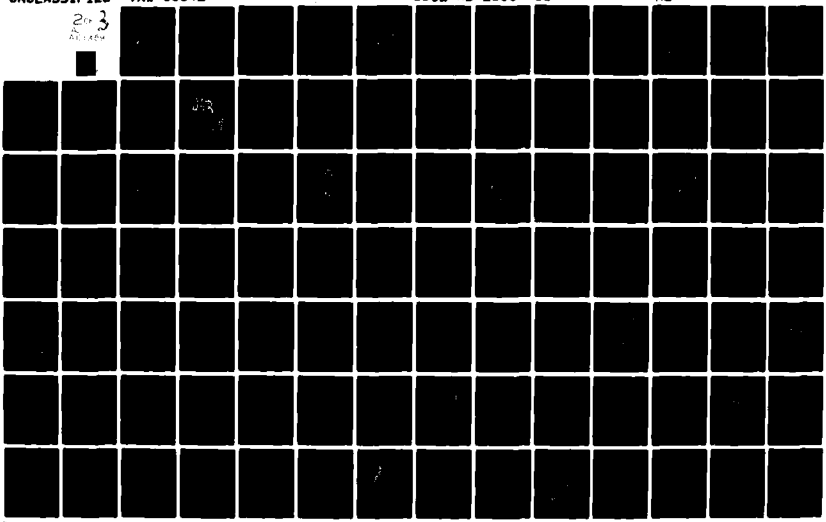


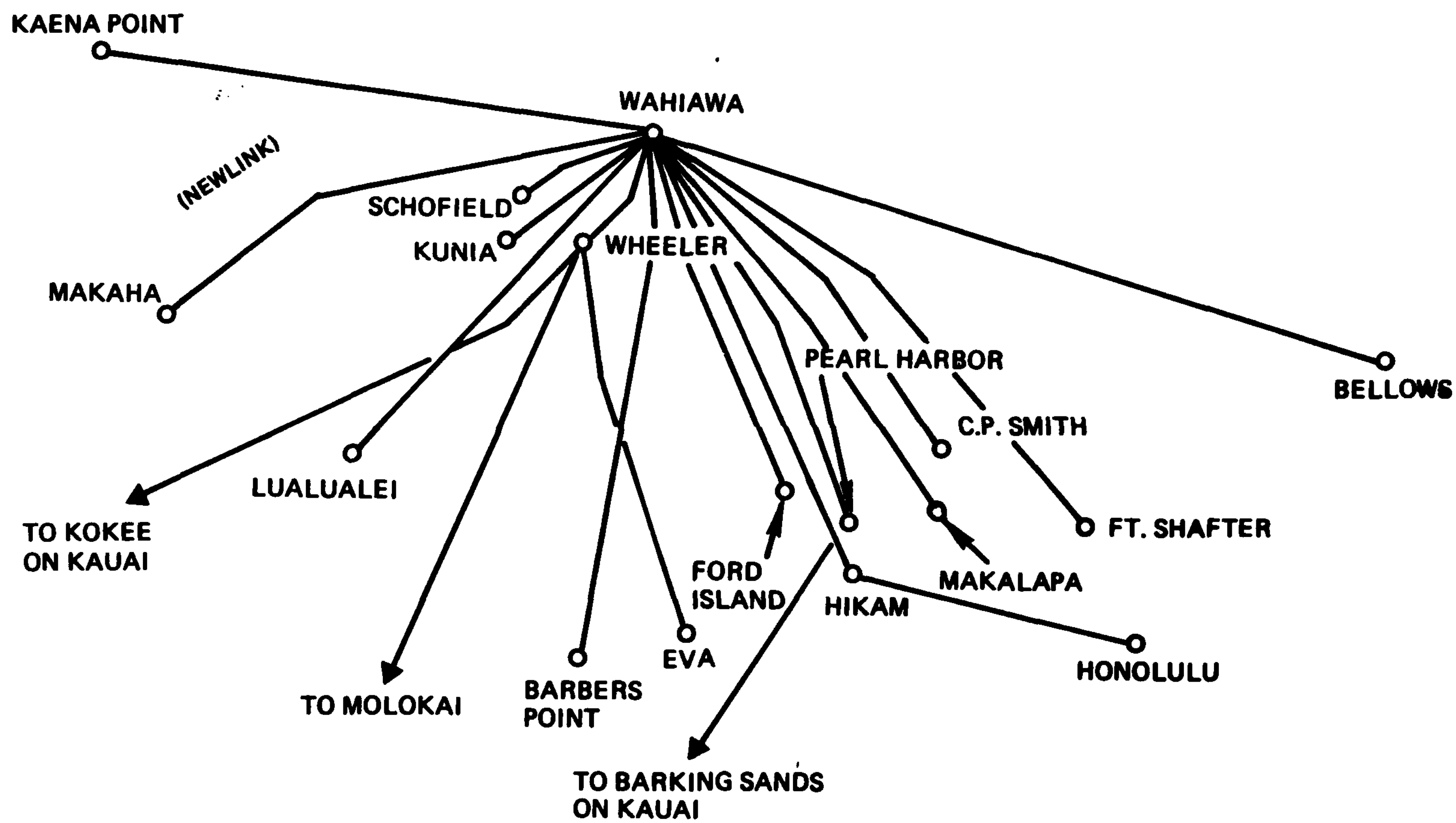



Figure 5-4. Candidate Single Star Network for Oahu

On the other hand, the proposed deletion of twelve of the candidate links spanning a total distance of about 78 miles requires an increase in the traffic on some of the remaining links connecting the user nodes to the central switching station at Wahiawa. Table 5-5 summarizes the modified data-rate requirements for the simplified communication network under consideration. In this connection it should be noted that these increased data-rate requirements will not stress projected capabilities of future communication systems even if link expandability is increased to 100 percent. In particular, due to the fact that the alternative transmission medium proposed here is a mm-wave LOS system, bandwidth requirements will pose no problem. Furthermore, efficient modems offering 4 bps/Hz are currently either available or under development by a number of companies identified in Table 5-6. It is reasonable to assume that within the next few years this technology will mature to the degree that such bandwidth-efficient modems will be commonplace.

One potential drawback of a single-star communication system is that failure of the central switching station can disrupt the total system. Although switching-station failures perhaps can be overcome by redundancy of equipment, this technique cannot rectify temporary outages due to intense rainfall near a switching station using mm-wave LOS as a transmission medium. Therefore, the double-star system shown in Figure 5-5 will be considered. The two switching stations for this network are located at Wahiawa and Pearl Harbor, with connection between users being made by switching at Pearl Harbor and Wahiawa as required. Distances between users and the central switching stations as well as applicable data-rate requirements are summarized in Table 5-7. Table 5-8 lists candidate links which can be deleted, connection between nodes being made by rerouting and switching.

5.3.2.2 MM-Wave LOS System. Due to the relatively short distances between users and central switching stations, two transmission media found to be ideal candidates for the proposed single- and double-star communication networks are mm-wave LOS digital radio systems and buried cable systems.

Table 5-5. User Connection and Data Requirements for Single-Star Oahu System

| Oahu Intra-Island User Connections | | Data-Rate Requirement Required | Modified | Distance (mi) |
|---|---|---|---|---|
| Barbers Point | Wahiawa | 1T1 | 5T1 | 12.2 |
| Bellows | Wahiawa | 1T1 | 3T1 | 17.4 |
| Camp Smith | Wahiawa | 3T1 | 10T1 | 9.9 |
| Ford Island | Wahiawa | 5T1 | 8T1 | 8.8 |
| Fort Shafter | Wahiawa | 2T1 | 3T1 | 3.4 |
| Hickam | Wahiawa | 6T1 + 6.176 Mbps | 151 + 6.176 Mbps | 11.2 |
| Kaena Point | Whaiawa | 2T1 | No change | 12.5 |
| Kunia | Wahaiwa | 3T1, 7.136, 3.191, 3,360 mbps | No Change | |
| Lualualei | Wahiawa | 2T1 | 3T1 | 10.0 |
| Makalapa | Wahiawa | 3T1 | 7T1 | 11.6 |
| Pearl Harbor | Wahiawa | 7T1 | 19T1 | 10.0 |
| Schoefield | Wahiawa | 1T1 | 2T1 | 3.4 |
| Wheeler | Wahiawa | 2T1 | 3T1 | 2.9 |
| Makaha* | Wahiawa | 1T1 | No Change | 11.6 |
| Wheeler | Ewa | 2T1 (One-way) | No change | 9.1 |
| Hickam | Honolulu | 1T1 (One-way) | No change | 7.2 |

Table 5-6. Bandwidth-Efficient Modem Characteristics

| MODULATION | Theoretical Performance | | Achievable Performance | | | | MANUFACTURER |
|---|---|---|---|---|---|---|---|
| | Efficiency (BIT/sec/Hz) | Eb/No at BER $10^{-6}$ | Efficiency (bit/sec/Hz) | Eb/No at BER=$10^{-6}$ | Bit Rate (MBps) | Carrier (GHz) | |
| QPSK | 2 | 10.6 | 1.3 | N.A. | 45 | 11 | Bell T3 System |
| | | | 2 | N.A. | 120 | 4,6 | Intelsat - V |
| 8-ary PSK | 3 | 13.8 | 2.25 | N.A | 90 | 11 | GTE Lenkurt |
| | | | 2.25 | 18.4 | 90.26 | 11 | Collins; MDR-11 |
| | | | 3 | 20.5 | | 6 | Collins; MDR-6 |
| | | | 2.3 | 18.5 | 90 | 11 | NEC |
| | | | 2.6 | 19.6 | 78 | 6 | NEC |
| | | | 3 | 22.5 | 90 | 6 | Raytheon |
| 16-ary QASK Rectangular | 4 | 14.5 | 3.33 | 21.6 | 400 | | NEC |
| | | | 3 | | 9.856 | 2 | Vidar; DRM2 |
| | | | 4 | | | | JPL |
| | | | 3.2 | | 90 | | Farinon |
| 3-level QPR | 2.14 | 12.7 | 1.8 | 15.5 | 6.3 | 2 | Avantek DR2C-96 |
| | | | 2.25 | 15.1 | 91 | 8 | BNR; RD-3 |
| | | | 2 | 15 | 79.2 | 11 | Microwave Associate |
| | | | 2 | | 26.1 | 4,8 | TRW; DRAMA |
| 7-level QPR | 4.2 | 17 | 4.1 | 23 | 12.63 | 2 | GTE Lenkurt |
| | | | 4 | | 26.1 | 8 | TRW; IR&D |

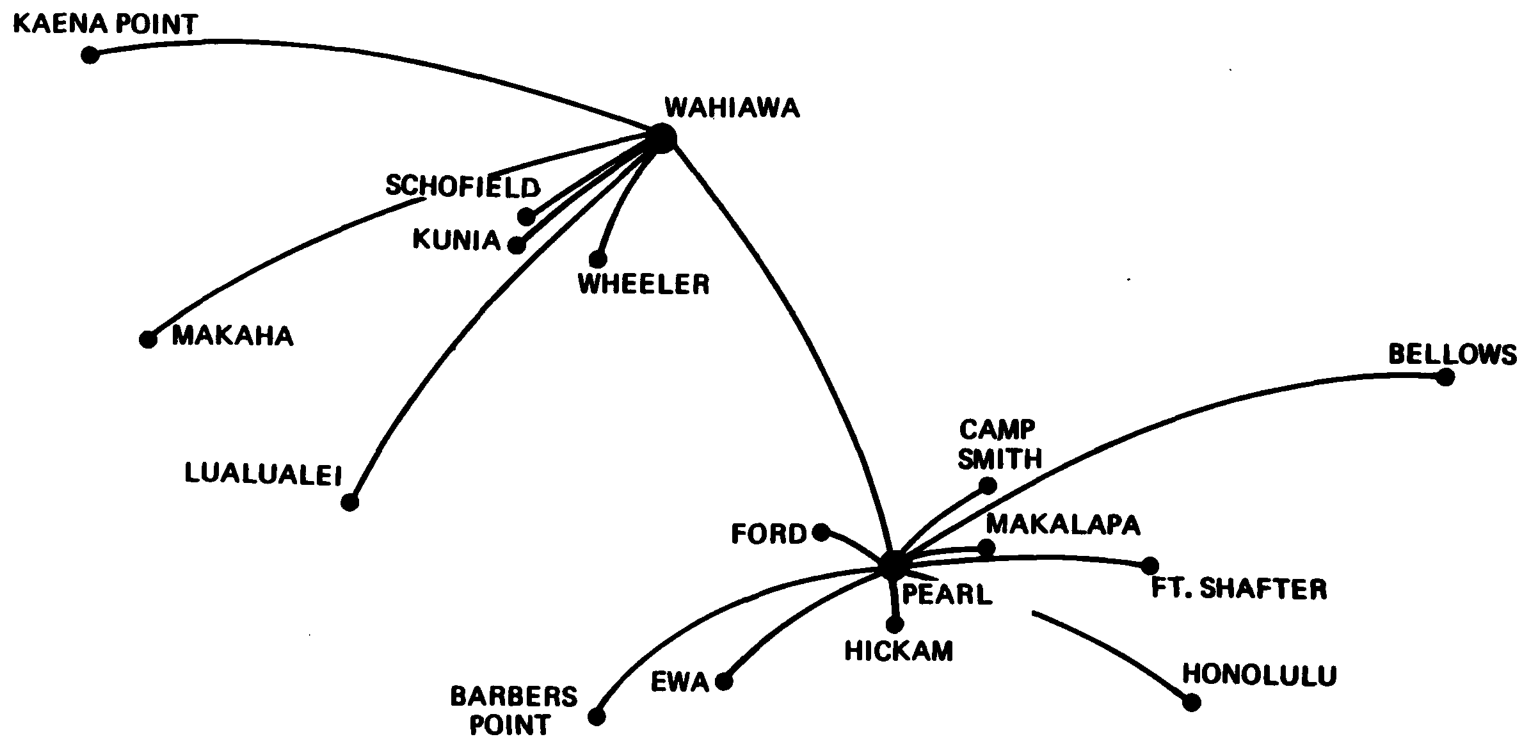



Figure 5-5. Candidate Double Star Network for Oahu

Table 5-7. Distances Between Switching Stations and Users for Double-Star Network

| Switching Stations | User | Distances (mi) | Date-Rate Requirements |
|---|---|---|---|
| Wahiawa | Kaena Point | 12.5 | 2T1 |
| | Makaha | 11.6 | 1T1 |
| | Schofield | 3.4 | 2T1 |
| | Kunia | 3.9 | 3T1, 7.136 Mbps<br>3.191 Mbps<br>3.360 Mbps |
| | Lualualei | 10.0 | 3T1 |
| | Wheeler | 2.9 | 3T1, 2T1 one-way |
| Pearl Harbor | Ford Island | 1.6 | 8T1 |
| | Barbers Point | 6.9 | 5T1 |
| | Ewa | 4.3 | 2T1 one-way |
| | Hickam | 1.3 | 16T1 + 6.176 Mbps |
| | Honolulu | 7.0 | 1T1 |
| | Fort Shafter | 5.4 | 3T1 |
| | Makalapa | 1.9 | 7T1 |
| | Bellows | 12.7 | 3T1 |
| | Camp Smith | 2.7 | 10T1 |
| Pearl Harbor | Wahiawa | 10.0 | 32T1, 6.176 Mbps<br>2T1 one-way |

Table 5-8. Candidate List of Deleted Links for Double-Star Oahu Network

| Two-Way Link | Date-Rate | Approximate Link Length (mi) |
|---|---|---|
| Makaha to Pearl Harbor | 1T1 | 16.1 |
| Schofield to Pearl Harbor | 1T1 | 10.5 |
| Wheeler to Ewa | 2T1 (one-way) | 9.1 |
| Wheeler to Pearl Harbor | 1T1 | 8.8 |
| Wheeler to Hickam | 1T1 | 10.0 |
| Barbers Point to Ford Island | 3T1 | 6.1 |
| Hickam to Camp Smith | 2T1 | 3.5 |
| Makalapa to Camp Smith | 2T1 | 1.5 |
| Hickam to Bellows | 2T1 | 13.0 |
| Wahiawa to Fort Shafter | 2T1 | 13.3 |
| Wahiawa to Bellows | 1T1 | 17.4 |
| Hickam to Honolulu | 1T1 | 7.2 |
| TOTAL | | 116.5 |

Key factors influencing selection of mm-wave bands for short-haul communications systems rather than the conventional centimetric bands are the increasing congestion at the lower frequencies and associated bandwidth limitation and interference, and the matured state of mm-wave technology which offers high reliability and compactness. However, mm-wave frequencies, unlike centrimetric frequencies, are subject to a greater degree to various attenuations such as absorption due to molecular oxygen and water vapor, attenuation due to rainfall, and scintillation fading.

Figure 5-6 identifies the 28- to 42-GHz, the 75- to 95-GHz, and the 125- to 140-GHz bands as three windows in the attenuation-versus-frequency curve caused by molecular oxygen and water vapor. Based upon both the maturity of technology and the value of the attenuation, the 28- to 42-GHz frequency band is the obvious choice for a short-haul mm-wave system.

Figure 5-7 shows excess-path attenuation as a function of both frequency and rainfall rate, this curve being used to estimate margin requirements in order to avoid outages due to moderate rainfall rates. However, link margin requirements can be expected to vary from link to link due to variations in the rainfall statistics over the island. For example, the normal annual rainfall for Honolulu based upon climatological data from 1941 to 1970 is 582 mm and the maximum average rainfall rate observed on 30 October 1978 over a period of three hours was 15.8 mm/hour, which would result in an excess attenuation of about 4 dB/km. In contrast, rainfall rates as high as 50 mm/hr were observed in the Honolulu area during a severe rain storm on 19 April 1974, such rates yielding about 11 dB/km of excess attenuation. Fortunately for communication networks, rates of this intensity generally are localized to cells and are of limited occurance.

A third category of loss that deserves consideration is scintillation fading, which is a type of short-term signal fluctuation caused by changes in the refractive index of the atmosphere due to temperature, pressure, and homogeniety variations. For the mm-wave links under consideration excess-path loss due to scintillation fading is approximately 2 to 3 dB, in accordance with Figure 5-8.

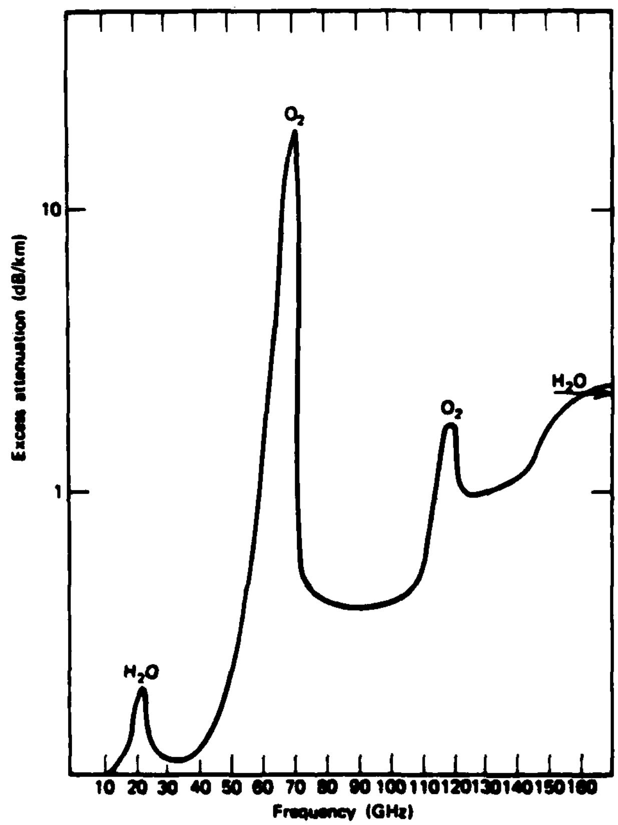



Figure 5-6. Attenuation of Electromagnetic Radiation in a Clear Atmosphere Due to Molecular Oxygen and Water Vapor

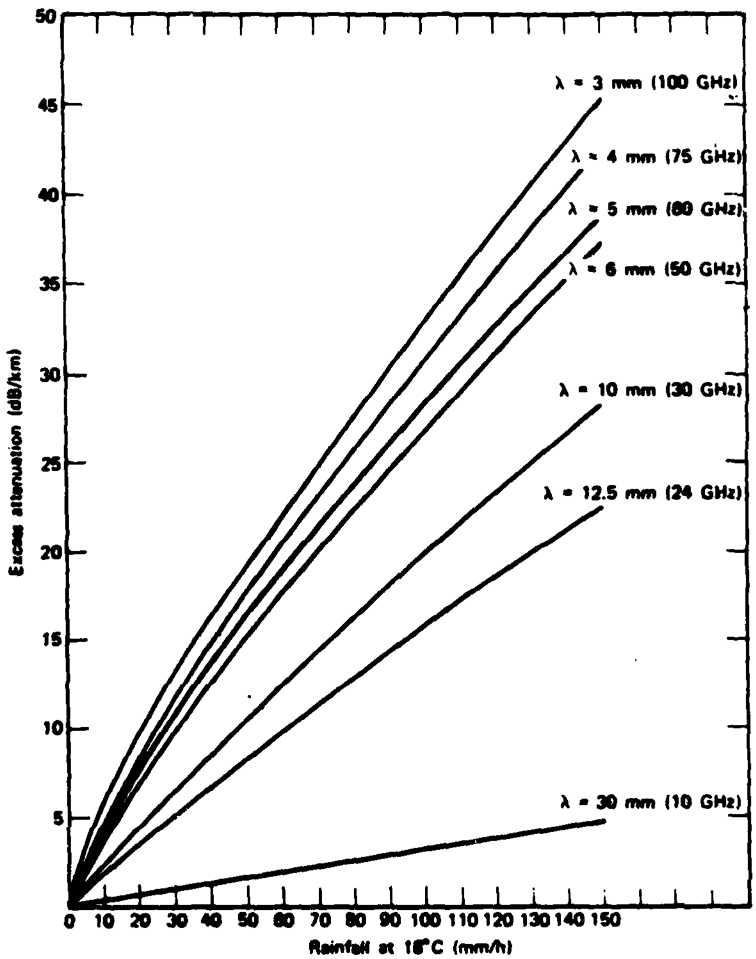



Figure 5-7. Excess Path Attenuation Due to Rainfall

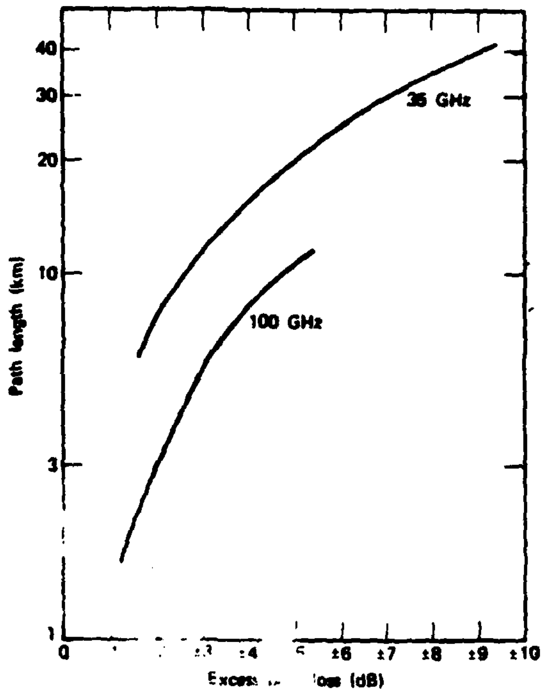


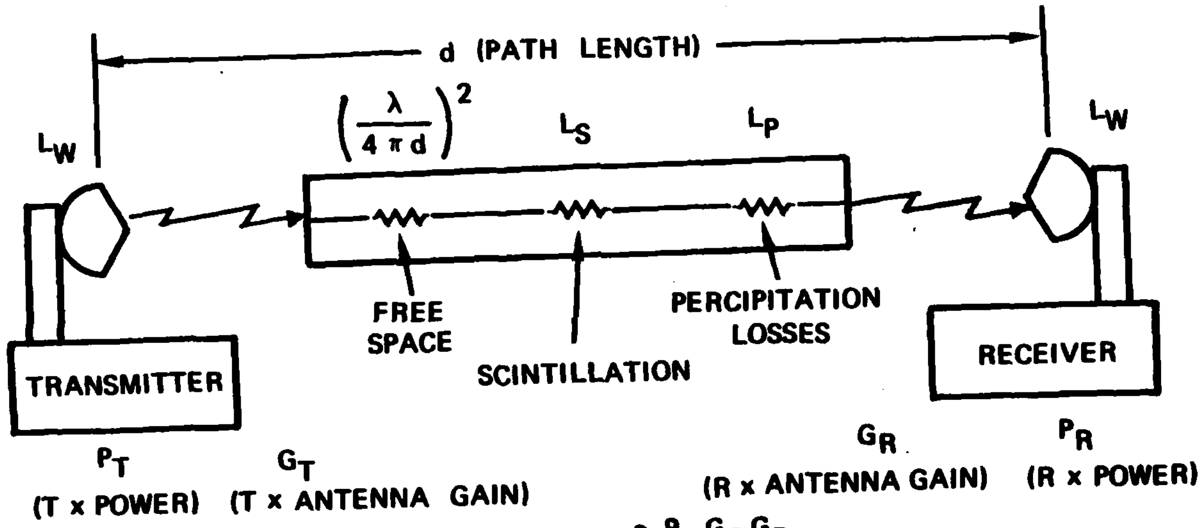

Figure 5-8. Scintillation Fading Values for 35 and 100 GHz

An additional loss mechanism that may have to be taken into account is attenuation due to fog, which is composed of very small, condensed water droplets suspended in air. On rare occasions the liquid-water content can become as high as 0.5 to 1.0 g/$m^3$ in very dense inland fogs and can be expected to produce attenuation rates comparable to those caused by rain with an intensity of about 2.5 to 5 mm/hr.

The various loss mechanisms which predominate at the higher frequencies fortunately can be offset by careful design and available technology. For example, due to the high frequencies involved, high antenna gains are possible for relatively small-diameter antennas and projected receiver noise figures and transmitter output powers are considered to be comparable to those currently attained by commercial digital radios operating in the centimetric bands. However, shorter repeater spacings from 5 to no more than 10 km are required to overcome the inherent free-space loss and to ensure adequate fade margins. The shorter spacing and elimination of redundant links previously noted in Tables 5-5 and 5-8 are of considerable importance for a reliable and cost-effective communication system network.

Figure 5-9 summarizes calculation of received signal level, $P_R$, for a mm-wave link in terms of transmitter power, $P_T$, path length, d, operating wavelength, $\lambda$, precipitation loss, $L_P$ scintillation loss $L_S$, waveguide loss $L_W$, and transmitter/receiver antenna gains, $G_T$ and $G_R$.

A typical mm-wave link budget calculation is summarized in Table 5-9, wherein the selected margin for precipitation loss corresponds to a heavy rainfall rate of about 50 mm/hr and transmitted output power of 2.0 Watts, path length of 5 km, frequency of 35 GHz, antenna gains of 48 dB, and receiver bandwidth of 15 MHz have been assumed. Using a modem whose bandwidth efficiency is 4 bps/Hz, the assumed bandwidth could accommodate a data rate of about 60 Mbps, which should be sufficient for traffic requirements between Wahiawa and Pearl Harbor for the double-star network configuration.




$$P_R = \left(\frac{\lambda}{4\pi d}\right)^2 \frac{P_T G_T G_R}{L_P L_S L_W}$$

Figure 5-9. Millimeter-Wave Radio System

Table 5-9. Summary of mm-Wave Budget Link Calculations for Path Length = 5 km

| Parameter | Formula | Value | Comments |
|---|---|---|---|
| $T_X$ Power | $-\log P_T$ | 3.0 dBW | 2 Watts |
| Space Loss | $\left(\frac{\lambda}{4\pi D}\right)^2$ | -137.3 | D=5 km; F=35 GHz |
| $T_X$ Antenna Gain | $+10 \log G_T$ | +48 dB | Antenna Diameter = 1.0 m |
| $R_X$ Antenna Gain | $+10 \log G_R$ | +48 dB | Antenna Diameter = 1.0 m |
| Scintillation Loss | $-10 \log L_S$ | -2.5 dB | |
| Waveguide Loss | $-10 \log L_W$ | -2.0 dB | |
| Precipitation Loss | $-10 \log L_P$ | -55.0 | 50 mm/hr (heavy rain) |
| $R_X$ Power | $P_R$ | -97.8 dBW | |
| Noise Power (15MHz) | +10 Log (ktb) | +126.8 dBW | T=1000$^O$K; B = 15 MHz |
| Signal to Noise Ratio | 10 Log ($P_R$/ktb) | +29 dB min | Require about 20 dB min |

Another key system design problem of any communications system is that of frequency allocation, and is particularly true in the centimetric bands. Fortunately, due to the 14-GHz wide window in the atmospheric absorption curve and use of bandwidth-efficient modems, this problem can readily be solved for the mm-wave bands. For example, if the maximum channel bandwidth is 20 MHz, then 700 channels should be available in the 28- to 42-GHz band and be ample to meet requirements for either the single- or the double-star network configurations proposed for Oahu.

A typical LOS mm-wave system is envisioned to consist of a number of repeaters spaced no more than 5 km apart and located on towers, as shown in Figure 5-10. Efficiency of a radio/repeater unit will be sufficiently high that much of its power requirements can be satisified by solar panels located on the towers. Key mm-wave digital radio features are summarized in Table 5-10, and a detailed assessment of mm-wave technology and prediction of capability for the 1900 to 2000 time period is documented in Appendix A. The proposed mm-wave system was based on these predictions.

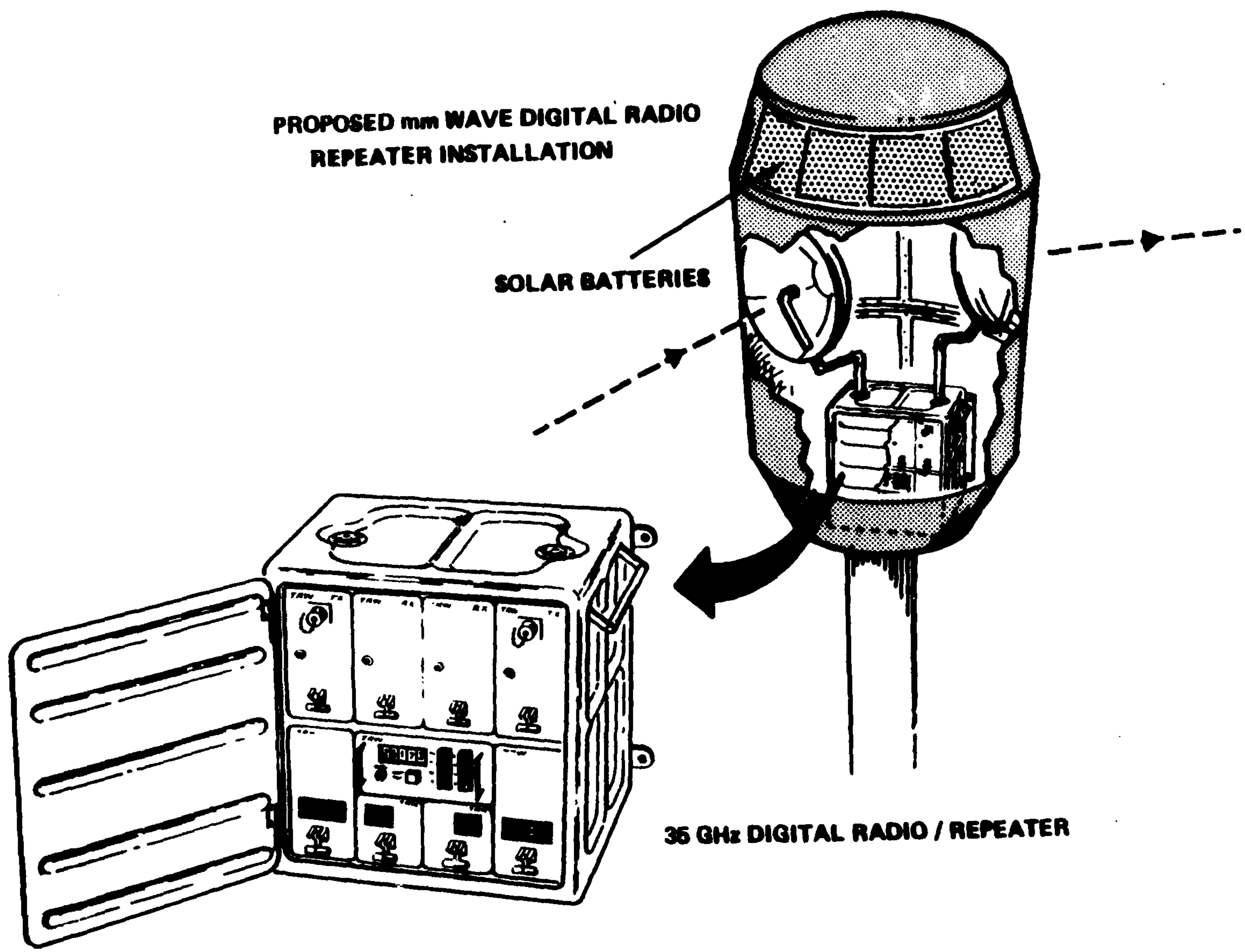



Figure 5-10. 35-GHz Digital Radio and Repeater Installation

Table 5-10. MM-Wave Digital Radio Key Features

| Parameter | Description |
|---|---|
| Tx Output Power (Watts) | 2.0 |
| Rx Noise Feature (dB) | 5.0 |
| Frequency Range (GHz) | 28 to 40 |
| Range per Hop (km) | 5 to 10 |
| Transmission Rate (Mbps) | 60 |
| Spectral Efficiency (bps/Hz) | 4.0 |
| Diversity Configuration | Hot standby |
| Power Requirements (Watts) | 150 |
| Size (in) | 20 x 20 x 20 |

5.3.3 Alternative System Design H-2. The second alternative transmission system proposed for Oahu Island is a buried cable system employing either coaxial tubes or optical fibers. Detailed discussion on characteristics and capability of each medium is given in Appendix A to this report.

Burial of a cable on private and public lands requires permission by the various parties and the state and national agenciees concerned, and obtaining of the needed right-of-way also may involve many time-consuming negotiations. This is in contrast with the mm-wave system, for which only the lands for construction of and for access roads to a few isolated relay stations are needed. In the present case it has been assumed that all terminals will be located inside military property.

On the other hand, a buried system has the following interesting advantages:

- Insensitivity to electromagnetic and radio interference
- Improved security over line-of-sight transmission systems
- In sensitivity to atmospheric phenomena such as precipitation and fading
- Elimination of frequency allocation problems
- Accomodation of high data rates
- Feasibility of upgrading system capacity without installation of new cables.

5.3.3.1 Assumptions. Assumptions cited in Section 2 are equally applicable here, and will remain effective along with the following additional assumptions for the buried system:

- Cable routes will parallel the existing road network.
- Although the trunk to Ford Island will not be included, a short section of submarine cable and necessary land cable could be used to connect Ford Island to nearby Pearl Harbor (Interconnection Point IP6)
- Only the minimum number of alternative routes will be proposed.

5.3.3.2 Buried Cable Routes. A preliminary design for the cable system is shown in Figure 5-11, which graphically portrays the logical connections of links required to support the user needs. Links are individually identified with a unique letter or letters and indicate the road distance between two nodes and the number of T1 channels on a particular link, the latter having been determined by taking the most direct route between two trunk endpoints. The same information is tabulated in Table 5-11. It should be noted that because of the proximity of Pearl Harbor and Hickam only one interconnection point (IP6) was selected to serve both locations. The primary routes include a total of 868.9 T1 channel-miles.

Actual cable routes on Oahu as shown in Figure 5-12 are generally parallel to existing roadways. Due to the fact that the design is hypothetical, no consideration has been given to existing outside plant facilities, right-of-ways, etc.

Because the highest traffic density is concentrated between Wahiawa, Wheeler, Makalapa, Pearl Harbor, Hickam (Links G, K, O, Q, R, and S), alternative routing is proposed. Only a minimum number of alternative routes for what appear to be the most essential links have been included. Figure 5-12 graphically displays the logical connections of the links, alternative links being identified in the same manner as the primary links discussed above. Primary and alternative routes include a total of 1684.3 T1 channel-miles.

5.3.3.3 Type of Cables. The two options available for the proposed buried cable system are armored cable with coaxial tubes, or optical fibers.

The standard Bell system uses armored cable employing 2.6/9.5-mm coaxial tubes, of which a pair can carry 4 T1 two-way channels, 28 T1 two-way channels, and 168 T1 two-way channels for L2, L3, and L4 operations respectively. One L3 cable with five working-tube pairs and one spare tube pair therefore can service almost half of the number of links while preserving ample growth capability. Two parallel runs of L3 cables will provide needed capacity for other links. Required cables and associated electronics are standard off-the-shelf items.

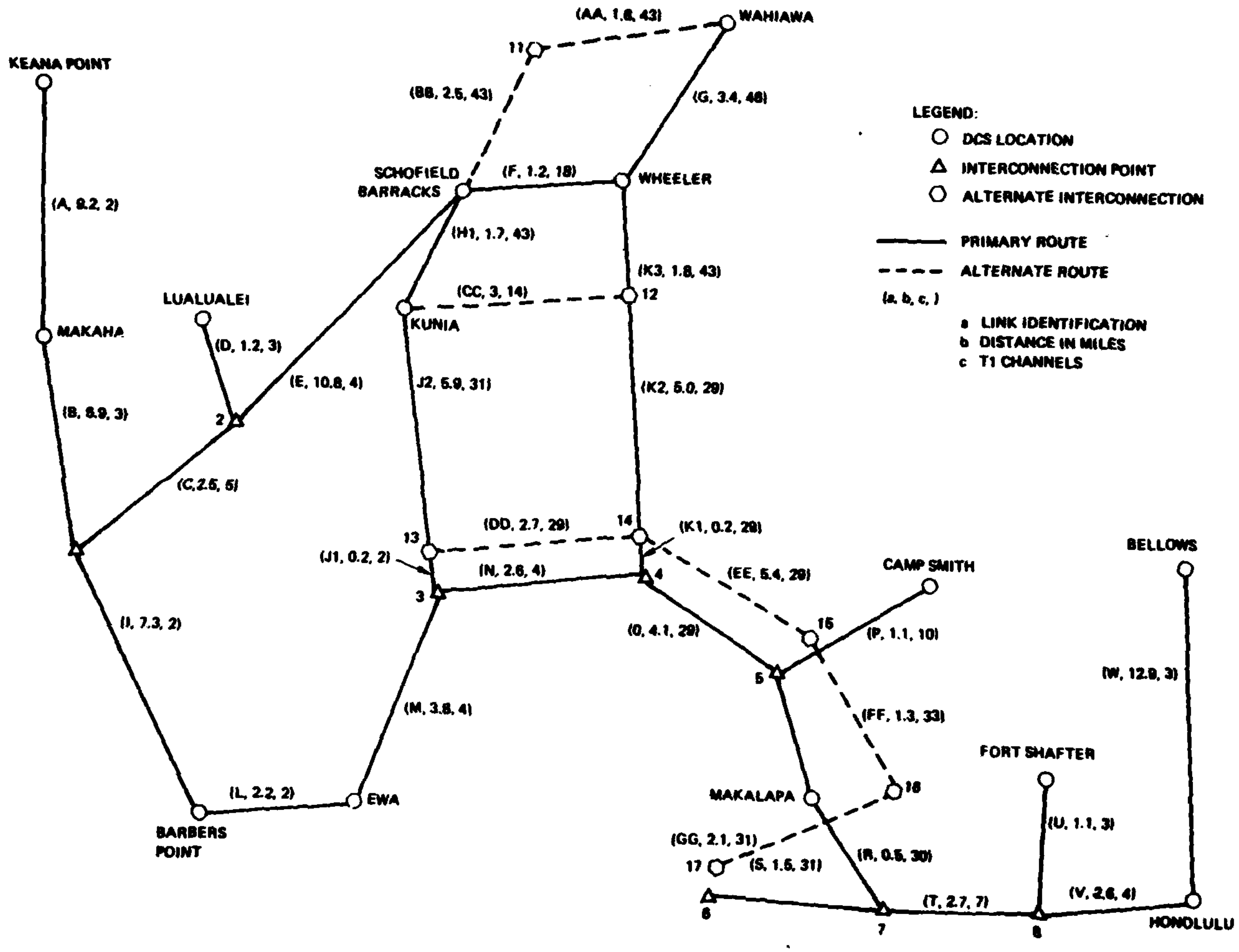



Figure 5-11. Primary and Alternate Cable Routes

Table 5-11. Channel-Miles of Buried Cable in Oahu Island

| Link Identification | Location A | Location B | Distance (Miles) | TI Channels |
|---|---|---|---|---|
| A | Kaena Point | Makaha | 9.2 | 2 |
| B | Makaha | IP 1* | 6.9 | 3 |
| C | IP 1 | IP 2 | 2.5 | 5 |
| D | IP 2 | Lualualei | 1.2 | 3 |
| E | IP 2 | Schofield Barracks | 10.8 | 4 |
| F | Schofield Barracks | Wheeler | 1.2 | 18 |
| G | Wheeler | Wahiawa | 3.4 | 46 |
| H | Kunia | Schofield Barracks | 1.7 | 14 |
| I | IP 1 | Barbers Pt. | 7.3 | 2 |
| J | Kunia | IP 3 | 6.1 | 2 |
| K | Wheeler | IP 4 | 7.0 | 29 |
| L | Barbers Pt. | Ewa | 2.2 | 2 |
| M | Ewa | IP 3 | 3.8 | 4 |
| N | IP 3 | IP 4 | 2.6 | 4 |
| O | IP 4 | IP 5 | 4.1 | 29 |
| P | IP 5 | Camp Smith | 1.1 | 10 |
| Q | IP 5 | Makalapa | 1.4 | 33 |
| R | IP 7 | Makalapa | 0.5 | 30 |
| S | IP 6 | IP 7 | 1.5 | 31 |
| T | IP 7 | IP 8 | 2.7 | 7 |
| U | IP 8 | Fort Shafter | 1.1 | 3 |
| V | IP 9 | Honolulu | 2.6 | 4 |
| W | Honolulu | Bellows | 12.9 | 3 |
| AA | IP** 11 | Wahaiawa | 1.8 | 43 |
| BB | IP 11 | Schofield Barracks | 2.5 | 43 |
| CC | IP 12 | Kunia | 3.0 | 14 |
| DD | IP 13 | IP 14 | 2.7 | 29 |
| EE | IP 14 | IP 15 | 5.4 | 29 |
| FF | IP 15 | IP 16 | 1.3 | 33 |
| GG | IP 16 | IP 17 | 2.1 | 31 |
| H1 | Kunia | Schofield Barracks | 1.7 | 43 |
| J1 | IP 3 | IP 13 | 0.2 | 2 |
| J2 | IP 13 | Kunia | 5.9 | 31 |
| K1 | IP 4 | IP 14 | 0.2 | 29 |
| K2 | IP 12 | IP 14 | 5.0 | 29 |
| K3 | IP 12 | Wheeler | 1.8 | 43 |

*All primary routes except J, J, and K do not change
**IP = Interconnection Point

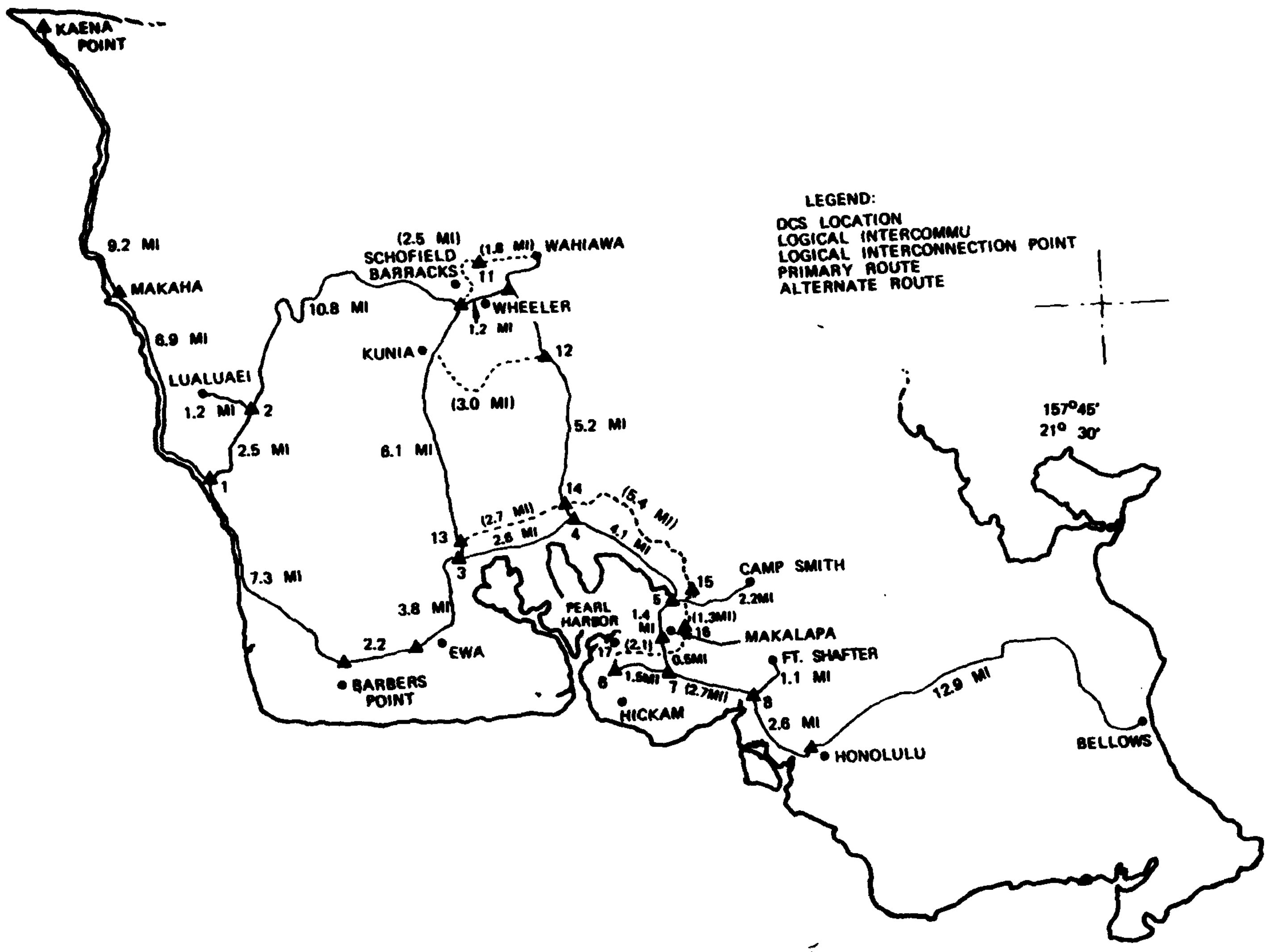



Figure 5-12. Actual Cable Routes in Hawaii

Fiber-optic cables such as Cornguide 3008D (Corning Glass Works) that currently are available exhibit attenuations of 1.5 dB/km at an operating wavelength of 1300 mm. However, because the longest link indicated in Figures 5-11 and 5-12 is only 12.9 km, no in-line repeater is required. In the future it is anticipated that the cost of this and similar optical cables will decrease substantially as the technology matures further, although the cost of actual cable burial will not. It therefore is essential that the length of the alternative routes is kept to the minimum.

A typical T3 fiber-optic system together with first- and second-level multiplexers is diagrammed in Figure 5-13. The first-level multiplexer accepts 24 voice channels and combines them into a T1 or 1.544-Mbps data stream. The second-level multiplexer accepts 28 T1 lines and combines them into a 44.736-Mbps data stream which in turn is fed to the optical transmitter. A block diagram of the optical transmitter as shown in Figure 5-14 and Table 5-12 summarizes the key features of the optical system.

## 5.4 Candidate Alternative Transmission System For Central Germany

The DCS in West Germany is currently being gradually upgraded and digitalized during the process of transition from DCS I to DCS II. Efforts in support of the two programs now being implemented (i.e., Frandfurt-Koenigstuhl-Vaihingen (FKV) and Digital European Backbone (DEB)) are briefly summarized in Section 5.4.1. Two alternative systems that are proposed for these programs are on airborne relay system and a buried cable system.

Characteristics of the buried cable system using either coaxial tubes or optical fibers has been discussed previously in Section 5.3.3. However, because implementation problems may arise in Germany, negotiations should be initiated with the German government to assure that the proposed cable system will be handled as a joint venture and that installation, initial cost, operation, and utilization will be shared among U.S. and German military forces and German civilian users.

The airborne relay system employing a tethered balloon is currently under development and test although further work is needed.

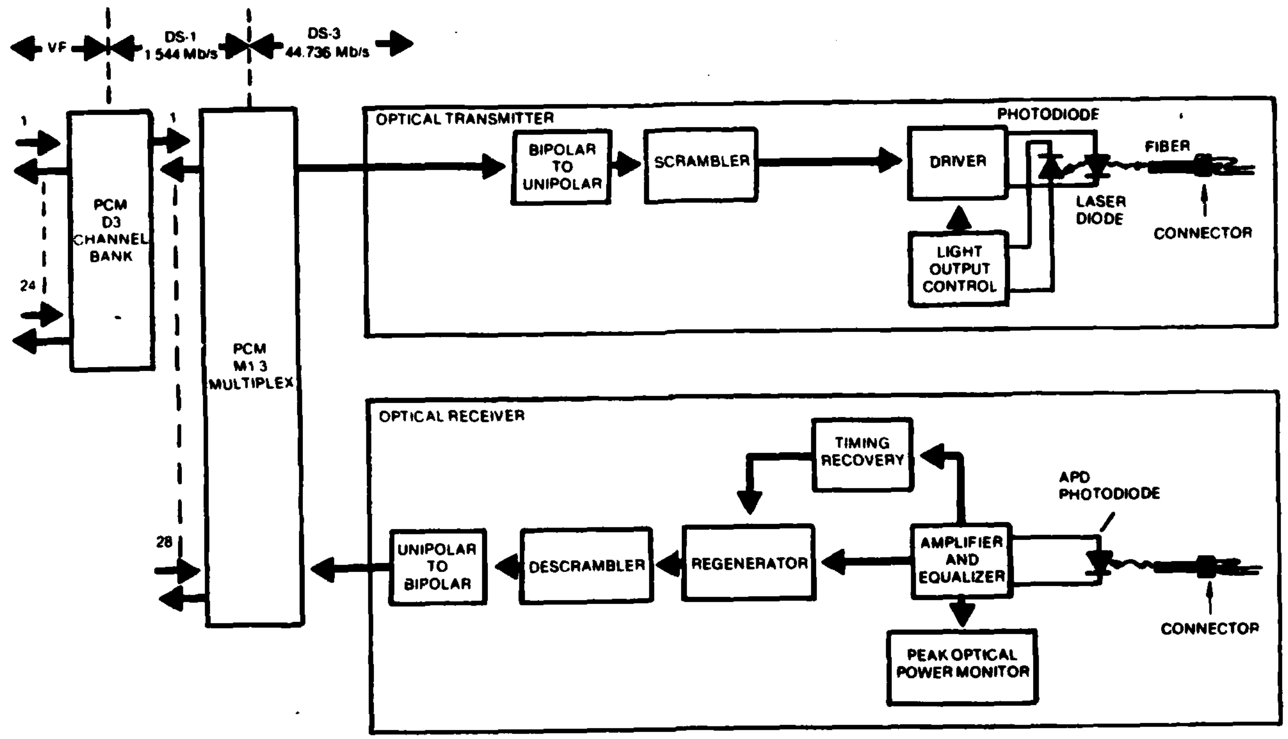



Figure 5-13. Fiber-Optic System Block Diagram

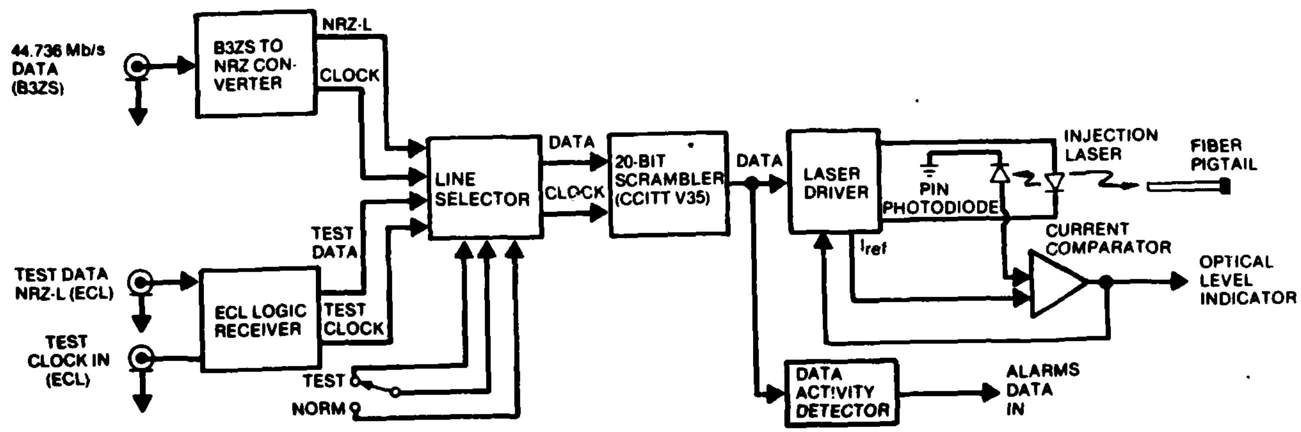



Figure 5-14. Optical Transmitter Block Diagram

Table 5-12. Key Features of an Optical Communications System

| Parameter | Description |
|---|---|
| General: | |
| Transmission Rate | 44.736 Mbps |
| Electrical Interface | B3ZS, DS-3, and NRZ ECL-Level |
| Optical: | |
| Transmitter Light Source | Injection laser |
| Receiver Detector | Photo diode |
| Fiber | Cornguide 3008D |
| Transmitter Output Power | 0 dB minimum |
| Receiver Sensitivity | -60 dBm for $10^{-9}$ BER |
| Operating Wave Length | 1300 nm |
| Electrical Power: | 115 VAC or -44 to -56 VDC |
| Alarms: | Loss of Rx data clock acquisition |
| | Loss of Tx input data |
| | Loss of Tx output power |

5.4.1 DCS Baseline in Central Germany

The region within the German Federal Republic that is under consideration is roughly bounded by Muhl-Wiesbaden-Heidelberg-Karlsruhe-Zweibrucken and is shown in Figure 5-15. The twenty-six known DCS sites within this region include the following:

| | |
|---|---|
| Bad Kreznach | Lindsey |
| Bann | Lohnsfeld |
| Baumholder | Mannheim |
| Boerfink | Milibocus |
| Darmstadt | Muhl |
| Donnersberg | Pirmasens |
| Heidelberg | Ramstein |
| Kaiserlautern | Schewetzingen |
| Karlsruhe | Seckenheim |
| Kinksback | Sembach |
| Koenigstuhl | Wiesbaden |
| Landstuhl | Worms |
| Langerkopf | Zweibrucken |

The above information was collected from numerous sources, the prime sources being information available from company files and from the Defense Communications Engineering Center (DCEC). This material is limited to trunk information and does not include circuit and traffic information which has not been made available for this study. Interconnecting trunks to locations outside this region also are not included.

5.4.1.1 DCS Existing in Central Germany. The DCS system existing as of July 1979 is shown in Figure 5-16. The radio links (identified by the letter M in the first position of the link identification number) principally use analog FDM-FM equipment with a few of the links already upgraded to digital modulation. The cable links (identified by an R or K in the first position of the link identification number) presently terminate in analog FDM-FM equipment. A summary of the terminal equipment, link distance, and channel capacity of each link is listed in Table 5-13.

5.4.1.2 DCS Planned in Central Germany. Current DCS plans are to upgrade all the radio links with digital modulation equipment by 1985. Equipment will be replaced on existing links, new links will be commissioned, and selected links will be deactivated. The replacement equipment is referred

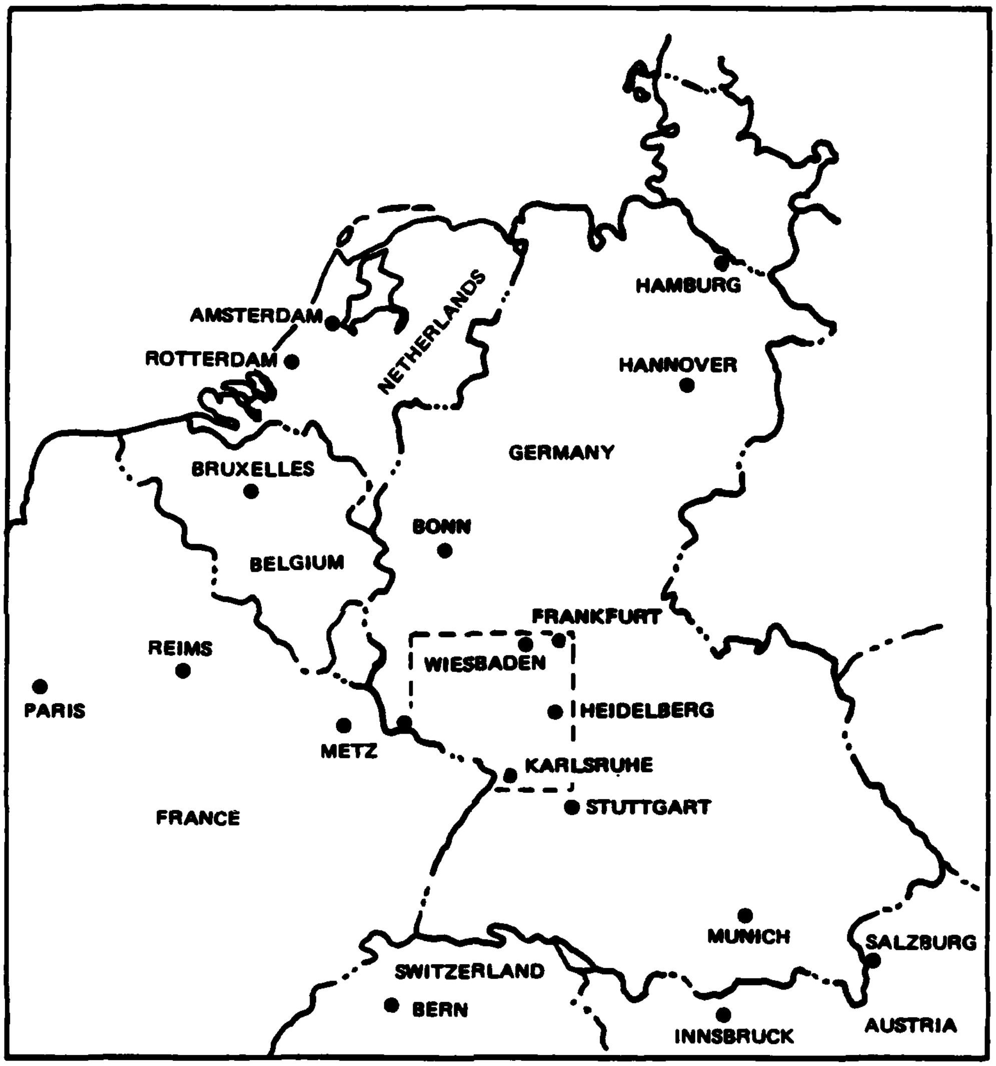



Figure 5-15. Central Germany Region of Interest

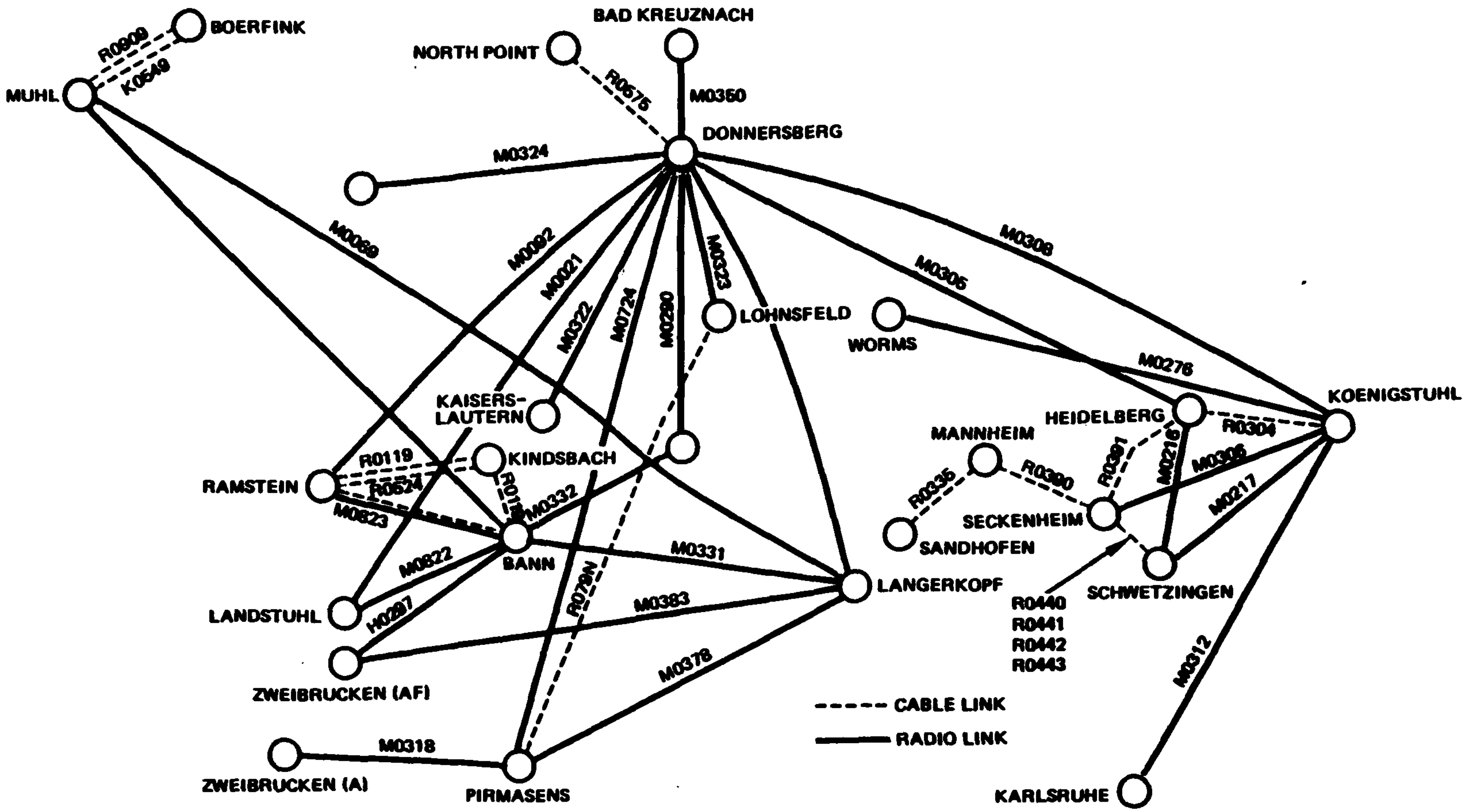



Figure 5-16. Existing Defense Communications System in Central Germany

Table 5-13. European Defense Communications System

1 July 1970

| No. | Link Identification | LINK: Location A | LINK: Location B | CHANNELS: Terminated Between A&B | CHANNELS: Terminated at A, B or Through | CHANNELS: Total | Terminal Equipment | Distance (Miles) |
|---|---|---|---|---|---|---|---|---|
| 1 | M0021 | Donnersberg | Landstuhl | 96 | 0 | 96 | AN/FRC-162 | 23 |
| 2 | M0305 | Donnersberg | Heidelberg | 84 | 36 | 120 | AN/FRC-80 | 36 |
| 3 | M0308 | Donnersberg | Koenigstuhl | 48 | 120 | 168 | AN/FRC-80 | 40 |
| 4 | M0350 | Donnersberg | Bad Krouznach | 48 | 12 | 60 | AN/FRC-80 | 16 |
| 5 | R0575 | Donnersberg | North Point | 25 | 0 | 25 | 25 PR Cable | 7 |
| 6 | M0324 | Donnersberg | Baumholder | 24 | 12 | 36 | AN/FRC-80 | 32 |
| 7 | M0322 | Donnersberg | Kaiserslautern | 84 | 96 | 180 | AN/FRC-80 | 15 |
| 8 | M0323 | Donnersberg | Lohnsfeld | 0 | 36 | 36 | AN/FRC-80 | 6 |
| 9 | M0092 | Donnersberg | Ramstein | 60 | 72 | 132 | LC-4 | 21 |
| 10 | M0724 | Donnersberg | Pirmasens | 96 | 156 | 252 | AN/FRC-80 | 31 |
| 11 | M0671 | Donnersberg | Langerkopf | 72 | 60 | 132 | LC-4 | 23 |
| 12 | M0290 | Donnersberg | Sembach | 48 | 72 | 120 | LC-4 | 8 |
| 13 | M0822 | Bann | Landstuhl | 72 | 48 | 120 | AN/FRC-162 | 23 |
| 14 | H079N | Pirmasens | Lohnsfeld | 0 | 36 | 36 | Cable | Unknown |
| 15 | M0318 | Pirmasens | Zweibrucken(A) | 36 | 24 | 60 | FM 120/6000 | 10 |
| 16 | M0378 | Pirmasens | Langerkopf | 72 | 60 | 132 | AN/FRC-80 | 12 |
| 17 | H0297 | Bann | Zweibrucken (AF) | 12 | 12 | 24 | AN/TRC-35 | 14 |
| 18 | M0383 | Langerkopf | Zweibrucken (AF) | 48 | 12 | 60 | Unknown | Unknown |
| 19 | M0069 | Langerkopf | Muhl | 24 | 60 | 84 | LC-8 | 45 |
| 20 | M0331 | Langerkopf | Bann | 96 | 36 | 132 | FM 120/6000 | 12 |
| 21 | M0823 | Ramstein | Bann | 96 & 4 Ports WB Data | 0 | 96 | AN/FRC-162 | 4 |
| 22 | M0346 | Muhl | Bann | 96 | 36 | 132 | LC-4 | 37 |
| 23 | M0332 | Sembach | Bann | 36 | 84 | 120 | FM 120/6000 | 14 |
| 24 | R0119 | Kindsbach | Bann | 0 | 120 | 120 | 200 PR Cable | 6 |
| 25 | R0119 | Kindsbach | Ramstein | 0 | 120 | 120 | 200 PR Cable | 3 |
| 26 | R0524 | Kindsbach | Ramstein | 100 | 0 | 100 | 100 PR Cable | 3 |
| 27 | R0909 | Muhl | Boerfink | 100 | 0 | 100 | 100 PR Cable | 9 |
| 28 | K0549 | Muhl | Boerfink | 24 | 84 | 108 | Cable | 9 |
| 29 | M0276 | Koenigstuhl | Worms | 48 | 24 | 72 | FM 120/6000 | 24 |
| 30 | M0217 | Koenigstuhl | Schwetzingen | 0 | 120 | 120 | AN/FRC-162 | 8 |
| 31 | M0216 | Heidelberg | Schwetzingen | 0 | 120 | 120 | AN/FRC-162 | 8 |
| 32 | R0304 | Koenigstuhl | Heidelberg | 600 | 0 | 600 | 600 PR Cable | Unknown |
| 33 | R0391 | Seckenheim | Heidelberg | | | Unknown | Cable | 7 |
| 34 | R0440, R0441, R0442, R0443 | Seckenheim | Schwetzingen | | | Unknown | Cable | Unknown |
| 35 | R0390 | Seckenheim | Mannheim | 300 | 0 | 300 | 300 PR Cable | Unknown |
| 36 | R0335 | Sandhofen | Mannheim | 200 | 0 | 200 | 200 PR Cable | Unknown |
| 37 | M0312 | Koenigstuhl | Karlsruhe | 60 | 0 | 60 | AN/FRC-80 | 30 |
| 38 | M0306 | Koenigstuhl | Seckenheim | 48 | 12 | 60 | AN/FRC-80 | 9 |

to as DRAMA radio, tentatively designated as AN/FRC-( ) ( ), and will be able to accommodate up to 16 ports at 1.544 Mbps each. Each port is designed to terminate a 24-channel PCM multiplex unit, which provides each link with a maximum capacity of 384 channels.

Detailed information pertaining to the cable links was not available, but it is assumed that these links will be upgraded to T1 lines with digital termination equipment. Upgrade will be accomplished by implementing the Digital European Backbone (DEB) Multiplex Configuration Stages I-IV and by installation of the Frankfurt-Koeenigstuhl-Vaihingen (FKV) system. Details of thes efforts will be discussed in the next section. The planned system is shown in Figure 5-17.

Information obtained on the existing DCS, DEB, and FKV systems is the best available at this time and may be used to establish a baseline for Central Germany. It also may be assumed that no new sites (i.e., physical locations) will be constructed for DCS III, but that equipment will be replaced or upgraded only at existing sites. Intended upgrading will implement the following activity.

a. DEB Stage I and FKV Stages I and II

The three radio links for DEB Stage I and the five radio links for FKV Stages I and II shown in Figure 5-18 are the initial links to be upgraded. Links with a specific number (i.e., Muhl-Langerkopf; M0069) are existing links being upgraded with the digital equipment, and links with a generic number (i.e., MOXXX) are new links that will be activated with the digital equipment. A summary of the terminal equipment, link distance, and channel capacity of each link is given in Table 5-14.

DEB Stage I went operational in late 1979.

b. DEB Stage II

Twenty radio links and one cable link for DEB Stage II are shown in Figure 5-19. This stage of the upgrade is characterized by upgrading of existing links, rechannelization of existing links, and establishment of new digital links. Link identification-specific or generic-number nomenclature symbolism is the same as that noted in Subsection a. above. A summary of the terminal equipment, link distance, and channel capacity of each link is given in Table 5-15.

DEB Stage II is programmed to go operational in FY 81-82.

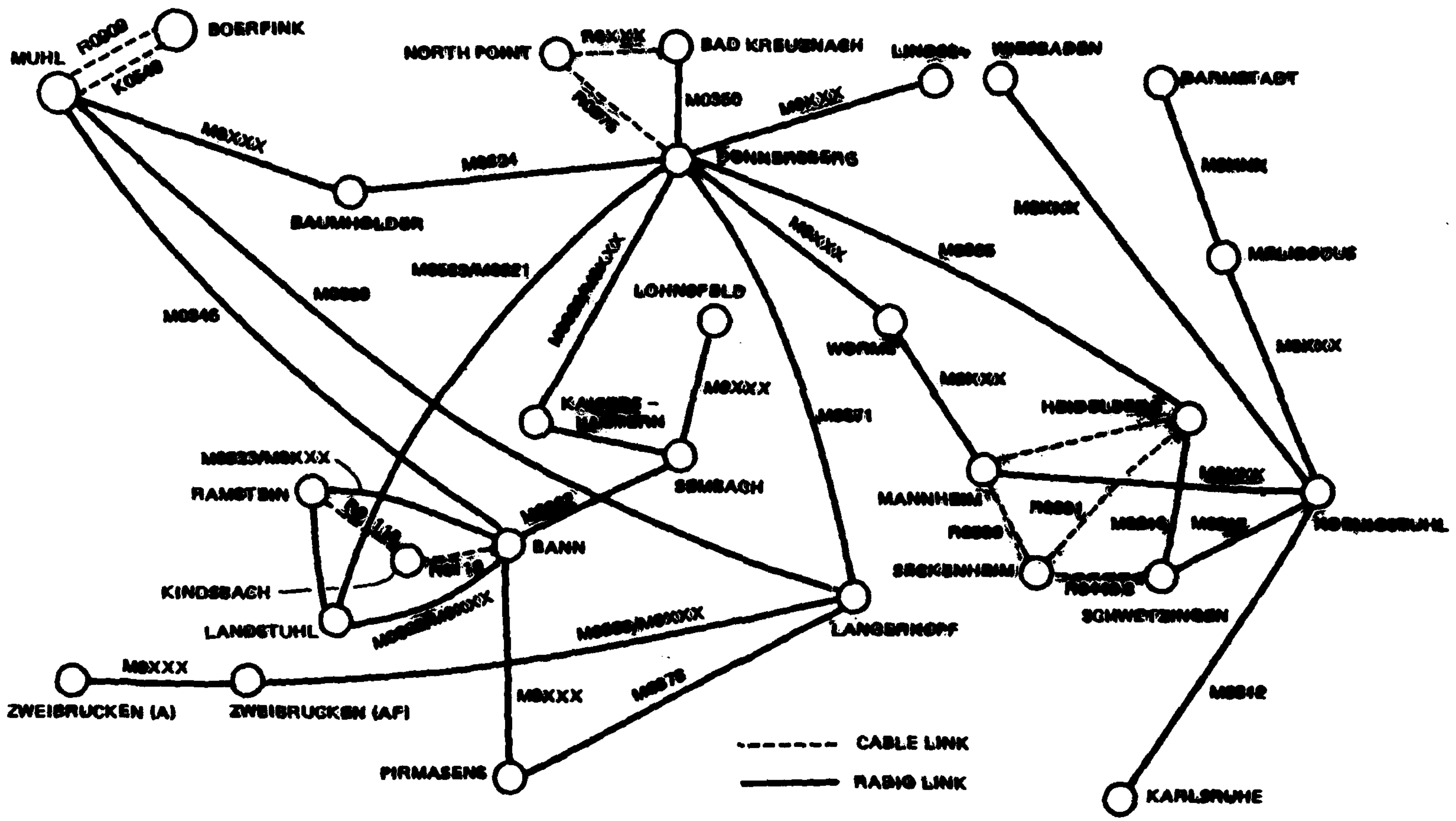



Figure 5-17. Planned Defense Communications System in Central Germany

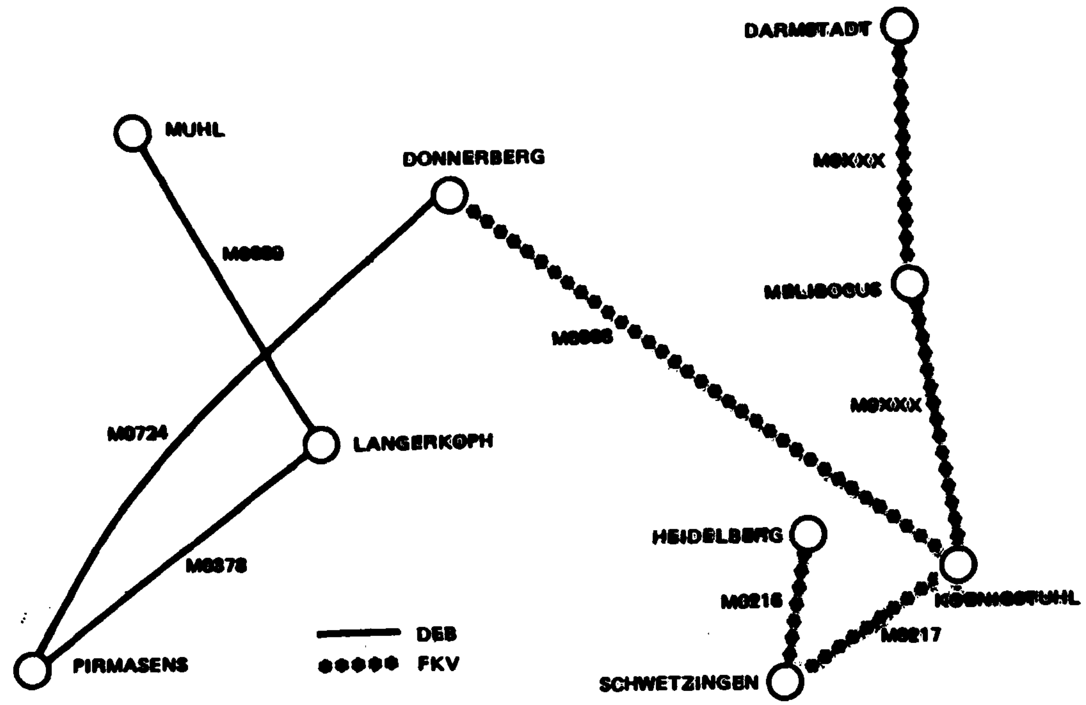



Figure 5-18. Digital European Backbone Stage I and Frankfurt-Koenigstuhl-Vihingen Stage I and II Systems

Table 5-14. Digital European Backbone (DEB) Stage I and FKV Stages I and II Link Characteristics

| | | LINK | | CHANNELS | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Link Identification | Location A | Location B | Terminated Between A&B | Terminated at A, B or Through | Total | Terminal Equipment | Distance (Miles) |
| 1 | M0378 | Pirmasens | Langerkopf | 72 | 60 | 132 | AN/FRC-80 | 12 |
| 2 | M0724 | Pirmasens | Donnersberg | 96 | 156 | 252 | AN/FRC-80 | 31 |
| 3 | M0069 | Muhl | Langerkopf | 24 | 60 | 84 | LC-8 | 45 |
| 4 | M0308 | Donnersberg | Koenigstuhl | 0 | 24 | 24 | AN/FRC-80 | 40 |
| 5 | M0217 | Schwetzingen | Koenigstuhl | 24 | 96 | 120 | AN/FRC-162 | 8 |
| 6 | M0216 | Schwetzingen | Heidelberg | 24 | 96 | 120 | AN/FRC-162 | 8 |
| 7 | M0XXX | Melibocus | Koenigstuhl | 0 | 120 | 120 | AN/FRC-162 | 22 |
| 8 | M0XXX | Melibocus | Darmstadt | 0 | 72 | 72 | AN/FRC-162 | 8 |

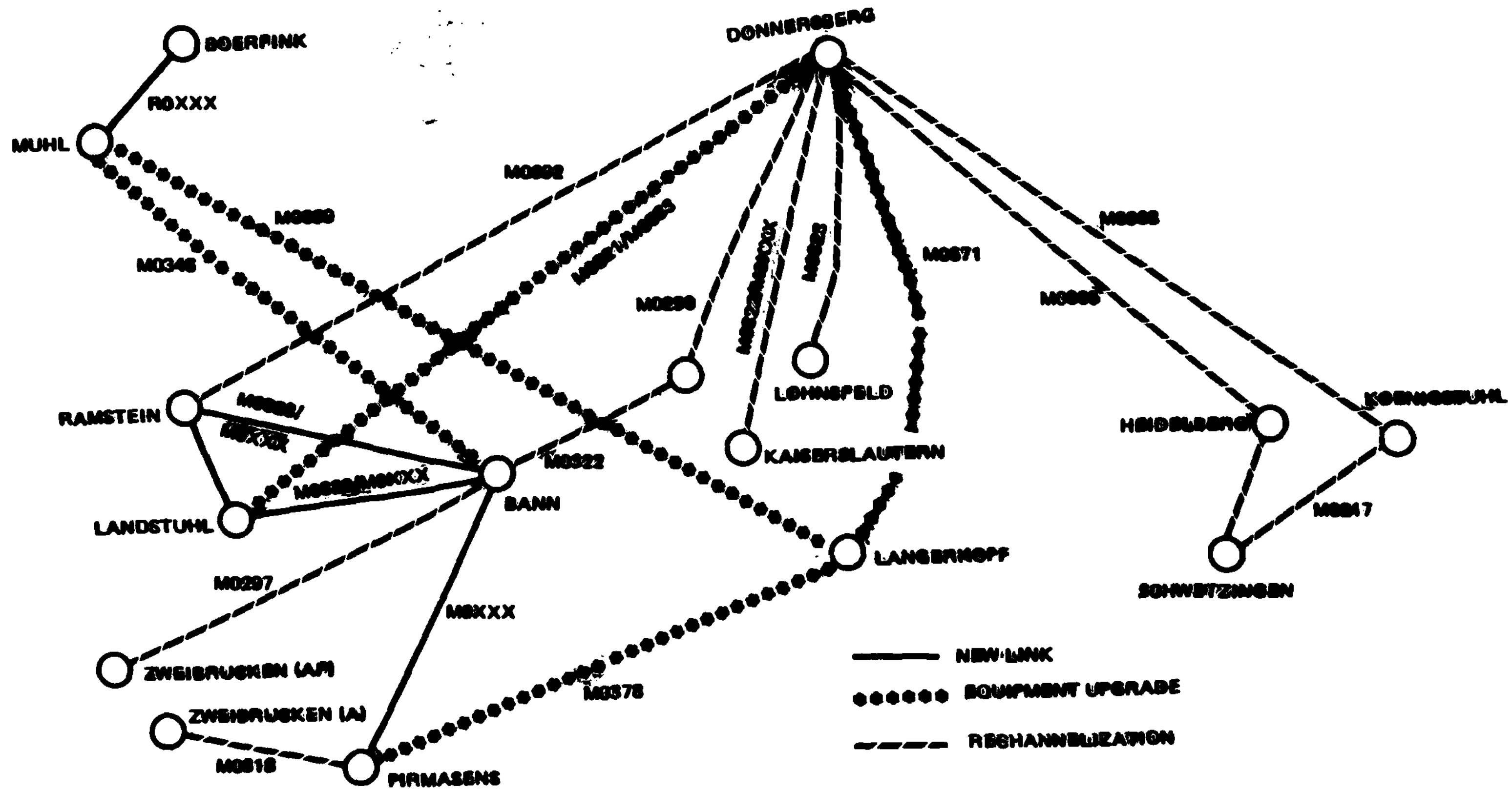



Figure 5-19. Digital European Backbone Stage II System

Table 5-15. Digital European Backbone (DEB) Stage II Link Characteristics

| | | LINK | | CHANNELS | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Link Identification | Location A | Location B | Terminated Between A&B | Terminated at A, B or Through | Total | Terminal Equipment | Distance (Miles) |
| 1 | M0322 | Donnersberg | Kaiserslautern | 0 | 84 | 84 | AN/FRC-80 | 15 |
| 2 | M0092 | Donnersberg | Ramstein | 36 | 36 | 72 | LC-4 | 21 |
| 3 | M0583 | Donnersberg | Landstuhl | 48 | 324 | 372 | AN/FRC-( ) | 23 |
| 4 | M0323 | Donnersberg | Lohnsfeld | 0 | 36 | 36 | AN/FRC-80 | 6 |
| 5 | M0290 | Donnersberg | Sembach | 36 | 36 | 72 | LC-4 | 8 |
| 6 | M0671 | Donnersberg | Langerkopf | 72 | 204 | 276 | AN/FRC-( ) | 23 |
| 7 | M0308 | Donnersberg | Koenigstuhl | 24 | 108 | 132 | AN/FRC-80 | 40 |
| 8 | M0305 | Donnersberg | Heidelberg | 0 | 12 | 12 | AN/FRC-80 | 36 |
| 9 | M0216 | Heidelberg | Schwetzingen | 0 | 48 | 48 | AN/FRC-162 | 8 |
| 10 | M0217 | Schwetzingen | Koenigstuhl | 0 | 48 | 48 | AN/FRC-162 | 8 |
| 11 | M0069 | Langerkopf | Muhl | 72 | 120 | 192 | AN/FRC-( ) | 45 |
| 12 | R0XXX | Boerfink | Muhl | 24 | 144 | 168 | Cable | 9 |
| 13 | M0346 | Bann | Muhl | 84 | 228 | 312 | AN/FRC-( ) | 37 |
| 14 | M0332 | Bann | Sembach | 36 | 96 | 132 | FM 120/8000 | 14 |
| 15 | M0XXX | Bann | Ramstein | 132 | 252 | 384 | AN/FRC-( ) | 5 |
| 16 | M0XXX | Bann | Landstuhl | 24 | 96 | 120 | AN/FRC-( ) | 3 |
| 17 | M0297 | Bann | Zweibrucken (AF) | 12 | 12 | 24 | AN/TRC-35 | 14 |
| 18 | M0XXX | Bann | Pirmasens | 24 | 276 | 300 | AN/FRC-( ) | 13 |
| 19 | M0378 | Langerkopf | Pirmasens | 84 | 228 | 312 | AN/FRC-( ) | 12 |
| 20 | M0318 | Zweibrucken(A) | Pirmasens | 36 | 24 | 60 | FM 120/8000 | 18 |
| 21 | M0XXX | Ramstein | Landstuhl | 24 & 4 Ports for WB Data | 156 | 180 | AN/FRC-( ) | 5 |

c. DEB Stage III

This stage does not apply to sites in Central Germany

d. DEB Stabe IV

Twenty-eight radio links and one cable link for DEB Stage IV are shown in Figure 5-20. The final stage of the upgrade also is characterized by upgrading of existing links, rechannelization of existing links, and establishment of new digital links, and link-identification nomenclature symbolism also is the same as described above. Where two link identifications are shown in Figure 5-20 it is assumed that only one link is planned, as the source documentation did not clearly reflect how the transition occured between the temal locations. Also, both link identifiers are shown in order to permit stages to be positively distinguished. A summary of the terminal equipment, link distance, and channel capacity for each link is tabulated in Table 5-16.

DEB Stage IV is programmed to go operational in FY 83-84.

5.4.1.3 Evolution of DEB and FKV Systems. Figure 5-21 is a graphic recapitulation of how the DEB and FKV systems evolved from the existing system.

A dash appearing in Table 5-17 indicates that no changes were implemented for the respective link during the phase. Also links in DEB Stage IV identified by an asterisk(*) were assumed to be deactivated during that stage. The latter assumption was based upon the fact that these links did not appear on the Stage-IV multiplex configuration and the projected European Connectivity 1985, and that an analysis of the trunk routing between two subscriber locations verified elimination of requirement for the link.

Except for the Muhl-Boerfink links, link characteristics are as noted previously in Table 5-15.

5.4.2 Alternative Design G-1. The first alternative transmission system design for Central Germany is on airborne relay system employing a tethered balloon. The purpose of this design is to examine potential utility of a tethered balloon for a small area that contains a dense user population.

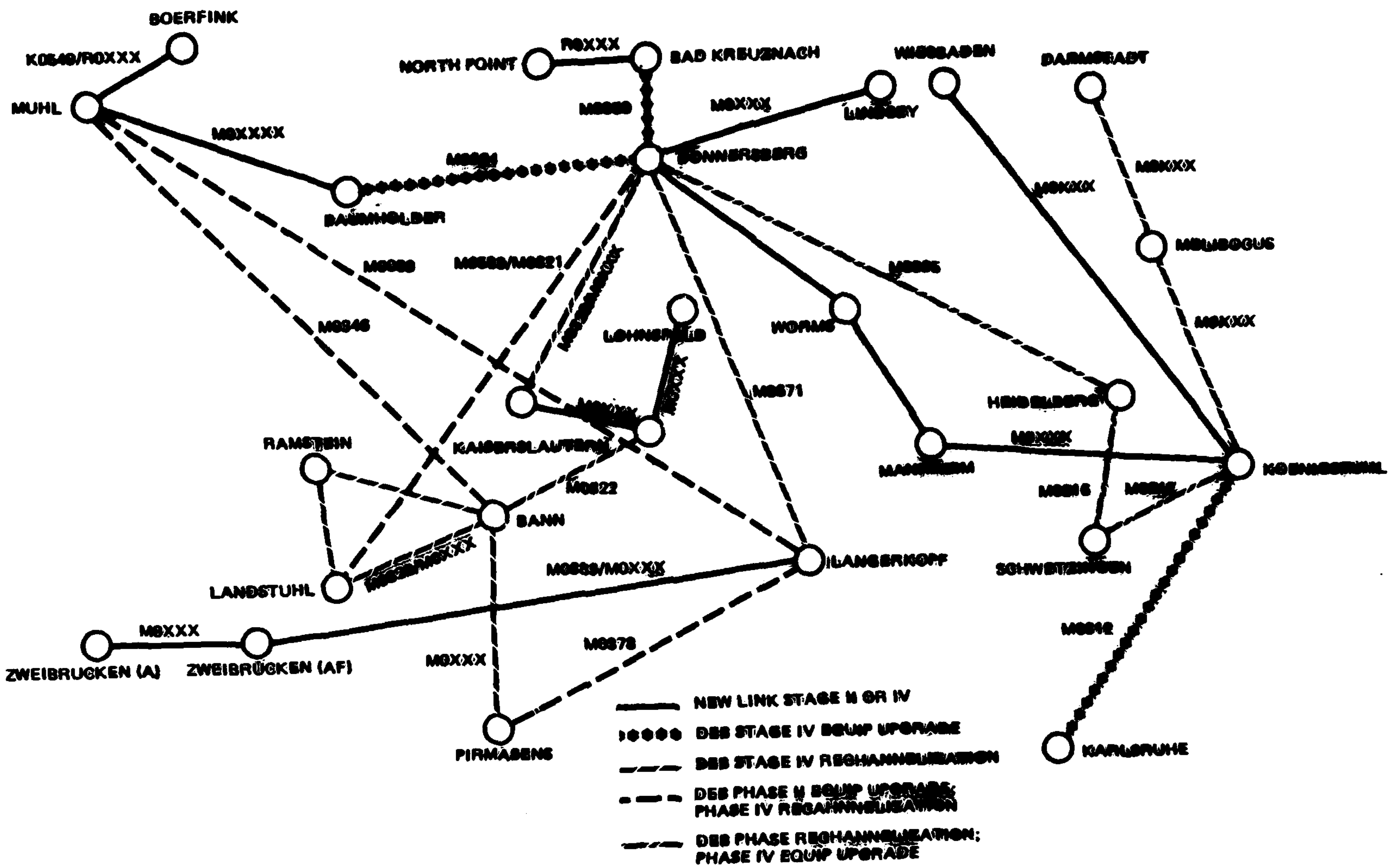



Figure 5-20. Digital European Backbone Stage IV System

Table 5-16. Digital European Backbone (DEB) Stage IV Link Characteristics

| No. | Link Identification | LINK Location A | LINK Location B | CHANNELS Terminated Between A&B | CHANNELS Terminated at A, B or Through | CHANNELS Total | Terminal Equipment | Distance (Miles) |
|---|---|---|---|---|---|---|---|---|
| 1 | M0XXX | Donnersberg | Lindsey | 48 | 24 | 72 | AN/FRC-( ) | 32 |
| 2 | M0305 | Donnersberg | Heidelberg | 96 | 192 | 288 | AN/FRC-( ) | 36 |
| 3 | M0XXX | Donnersberg | Worms | 48 | 72 | 120 | AN/FRC-162 | 20 |
| 4 | M0XXX | Donnersberg | Kaiserslautern | 60 | 324 | 384 | AN/FRC-( ) | 7 |
| 5 | M0583 | Donnersberg | Landstuhl | 48 | 336 | 384 | AN/FRC-( ) | 23 |
| 6 | M0324 | Donnersberg | Baumholder | 24 | 240 | 264 | AN/FRC-( ) | 32 |
| 7 | R0XXX | Bad Kreuznach | North Point | 24 | 0 | 24 | Cable | Unknown |
| 8 | M0XXX | Kaiserslautern | Sembach | 24 | 216 | 240 | AN/FRC-( ) | 6 |
| 9 | M0XXX | Lohnsfeld | Sembach | 0 | 36 | 36 | AN/FRC-( ) | 3 |
| 10 | M0XXX | Muhl | Baumholder | 24 | 192 | 216 | AN/FRC-( ) | 13 |
| 11 | M0346 | Muhl | Bann | 72 | 288 | 360 | AN/FRC-( ) | 37 |
| 12 | M0XXX | Ramstein | Bann | 120 | 240 | 360 | AN/FRC-( ) | 5 |
| 13 | M0XXX | Landstuhl | Bann | 24 | 168 | 192 | AN/FRC-( ) | 3 |
| 14 | M0XXX | Pirmasens | Bann | 24 | 360 | 384 | AN/FRC-( ) | 13 |
| 15 | M0XXX | Sembach | Bann | 36 | 348 | 384 | AN/FRC-( ) | 10 |
| 16 | M0378 | Pirmasens | Langerkopf | 48 | 276 | 324 | AN/FRC-( ) | 12 |
| 17 | M0069 | Muhl | Langerkopf | 72 | 192 | 264 | AN/FRC-( ) | 45 |
| 18 | M0XXX | Zweibrucken(AF) | Langerkopf | 24 | 120 | 144 | AN/FRC-( ) | 21 |
| 19 | M0XXX | Zweibrucken(AF) | Zweibrucken(A) | 24 | 96 | 120 | AN/FRC-( ) | 3 |
| 20 | M0XXX | Landstuhl | Ramstein | 24 | 168 | 192 | AN/FRC-( ) | 5 |
| 21 | M0350 | Donnersberg | Bad Kreuznach | 24 | 48 | 72 | AN/FRC-( ) | 16 |
| 22 | M0XXX | Worms | Mannheim | 36 | 96 | 132 | AN/FRC-162 | 12 |
| 23 | M0218 | Heidelberg | Schwetzingen | 24 | 336 | 360 | AN/FRC-( ) | 6 |
| 24 | M0217 | Koenigstuhl | Schwetzingen | 24 | 144 | 168 | AN/FRC-( ) | 8 |
| 25 | M0XXX | Koenigstuhl | Mannheim | 24 | 144 | 168 | AN/FRC-162 | 12 |
| 26 | M0312 | Koenigstuhl | Karlsruhe | 48 | 48 | 96 | AN/FRC-( ) | 30 |
| 27 | M0XXX | Koenigstuhl | Wiesbaden | 24 | 24 | 48 | AN/FRC-162 | 20 |
| 28 | M0XXX | Koenigstuhl | Melibocus | 0 | 120 | 120 | AN/FRC-162 | 22 |
| 29 | M0XXX | Melibocus | Darmstadt | 0 | 72 | 72 | AN/FRC-162 | 8 |

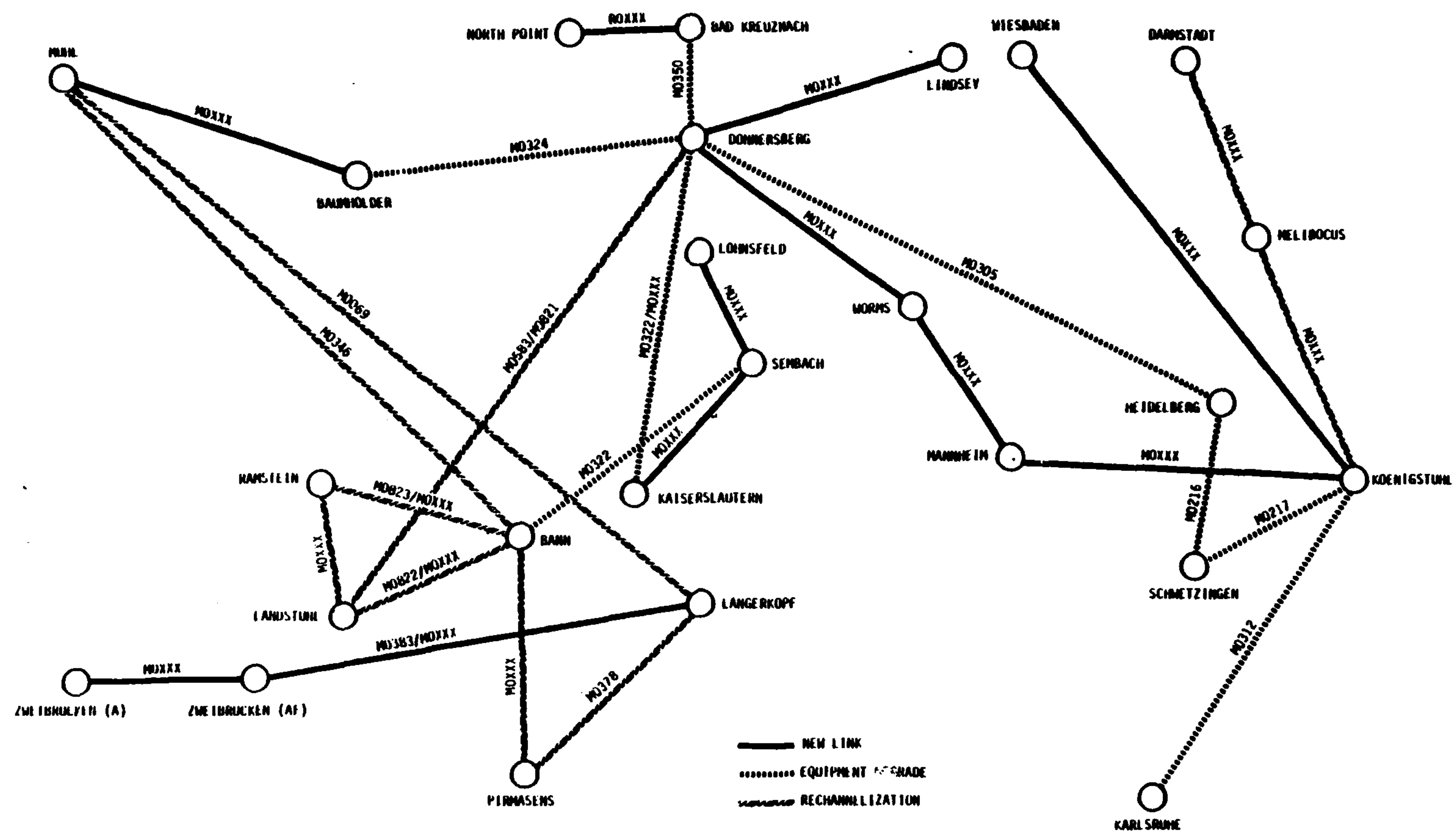



Figure 5-21. Evolution of Digital European Backbone (DEB) and FKV Systems

Table 5-17. Evolution of DEB and FKV Radio Links

Legend: A - Analog
D - Digital
X - Deactivated
* - Deactivation Assumed

| No. | Link Identification | LINK: Location A | LINK: Location B | Existing DCS | DEB I | FKV | DEB II | DEB IV |
|---|---|---|---|---|---|---|---|---|
| 1 | M0821/ M0583 | Donnersberg | Landstuhl | D | - | - | D | D |
| 2 | M0305 | Donnersberg | Heidelberg | A | - | - | A | D |
| 3 | M0308 | Donnersberg | Koenigstuhl | A | - | A | A | X* |
| 4 | M0350 | Donnersberg | Bad Kreuznach | A | - | - | - | D |
| 5 | M0324 | Donnersberg | Baumholder | A | - | - | - | D |
| 6 | M0322/ M0XXX | Donnersberg | Kaiserslautern | A | - | - | A | D |
| 7 | M0323 | Donnersberg | Lohnsfeld | A | - | - | A | X* |
| 8 | M0092 | Donnersberg | Ramstein | A | - | - | A | X* |
| 9 | M0724 | Donnersberg | Pirmasens | A | A | - | X | - |
| 10 | M0671 | Donnersberg | Langerkopf | A | - | - | D | - |
| 11 | M0290 | Donnersberg | Sembach | A | - | - | A | X* |
| 12 | M0822/ M0XXX | Bann | Landstuhl | D | - | - | D | D |
| 13 | M0318 | Pirmasens | Zweibrucken(A) | A | - | - | A | X* |
| 14 | M0378 | Pirmasens | Langerkopf | A | A | - | D | D |
| 15 | H0297 | Bann | Zweibrucken(AF) | A | - | - | A | X* |
| 16 | M0383/ M0XXX | Langerkopf | Zweibrucken(AF) | A | - | - | - | D |
| 17 | M0069 | Langerkopf | Muhl | A | A | - | D | D |
| 18 | M0331 | Langerkopf | Bann | A | - | - | X | - |
| 19 | M0823/ M0XXX | Ramstein | Bann | D | - | - | D | D |
| 20 | M0346 | Muhl | Bann | A | - | - | D | D |
| 21 | M0322 | Sembach | Bann | A | - | - | A | D |
| 22 | M0276 | Koenigstuhl | Worms | A | - | - | - | X* |
| 23 | M0217 | Koenigstuhl | Schwetzingen | D | - | D | D | D |
| 24 | M0216 | Heidelberg | Schwetzingen | D | - | D | D | D |
| 25 | M0312 | Koenigstuhl | Karlsruhe | A | - | - | - | D |
| 26 | M0306 | Koenigstuhl | Seckenheim | A | - | - | - | X* |
| 27 | M0XXX | Koenigstuhl | Melibocus | - | - | D | - | D |
| 28 | M0XXX | Darmstadt | Melibocus | - | - | D | - | D |
| 29 | M0XXX | Bann | Pirmasens | - | - | - | D | D |
| 30 | M0XXX | Ramstein | Landstuhl | - | - | - | D | D |
| 31 | M0XXX | Donnersberg | Lindsey | - | - | - | - | D |
| 32 | M0XXX | Donnersberg | Worms | - | - | - | - | D |
| 33 | M0XXX | Sembach | Kaiserslautern | - | - | - | - | D |
| 34 | M0XXX | Sembach | Lohnsfeld | - | - | - | - | D |
| 35 | M0XXX | Muhl | Baumholder | - | - | - | - | D |
| 36 | M0XXX | Zweibrucken(AF) | Zweibrucken(A) | - | - | - | - | D |
| 37 | M0XXX | Worms | Mannheim | - | - | - | - | D |
| 38 | M0XXX | Koenigstuhl | Mannheim | - | - | - | - | D |
| 39 | M0XXX | Koenigstuhl | Wiesbaden | - | - | - | - | D |

5.4.2.1 Characteristics for the Densely Populated Area. The size of the proposed densely populated study area in Central Germany is roughly 120 x 100 km. This area contains 24 communication nodes and a few repeater stations located in the Rhine River valley and extending to the rolling-terrain region. The existing communication systems mainly consist of analog FM line-of-sight links, or troposcatter systems and a few coaxial cable links.

Several documents that have served to provide traffic information in this area include the European Digital Backbone multiplexing plan, which was used to establish the baseline trunking requirement. After completion of Phase-IV improvement and modification the existing network capacity will be assumed capable of satisfying that requirement by the late 1980s and early 1990s.

However, present study interest is limited only to the traffic that originated and terminated in the study area, so that any traffic terminated at the communication nodes and/or originated from outside the area and vice versa will not be considered. In addition, all through traffic will be neglected.

Figure 5-22 summarizes the communication nodes and the end-to-end traffic capability in terms of number of T1 channels between the nodes in the study area. This chart was generated mainly on the basis of information provided in the European Digital Backbone multiplexing plan and shows that there are approximately 100 T1 channels between the various communication nodes within the area. In addition, there also is one wideband data channel equivalent to four T1 channels between Ramstein and Landstuhl. Figure 5-23 indicates the geographical distribution of the traffic and of the communications links upon completion of the DEB Stage-IV update. In general, each T1 channel carries 1.544 Mbps of data, which correspond to 24 telephone signals at 64 Kbps each. Thus the capacity requirement in the area is approximately 60 Mbps, but can be smaller if the telephonic message data rate is reduced from 64 Kbps to smaller values such as 32, 16, 9.6 or even 2.4 Kbps.

| | BFK | WBN | DST | DON | MUL | LFD | RBN | SEN | KLN | KSL | BAN | (SCW) SWN | HDG | LDL | LKF | ZBN | ZWE | PMS | KRE | WMS | LSY | MHN | BDK | NOP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BFK | | | | | 1 | | 1 | | | | 2 | | | | 1 | | | | | | | | | |
| WBN | | | | 1 | | | | | | 1 | | | | | | | | | | | | | | |
| DST | | | | | | | | | | | | | | | | | | | | | | | | |
| DON | | 1 | | | | | 4 | 1 | 2½ | | 3 | | 4 | 2 | 3 | | | 4½ | | 2 | 1 | | 1 | |
| MUL | 1 | | | | | | 1 | 1 | | | | | | | 3 | | | | | | | | | |
| LFD | | | | | | | | | | | | | | | | | | 1½ | | | | | | |
| RBN | 1 | | | 4 | 1 | | | 2 | 2 | | 5 | | | 1 + WIDEBAND 4 TI | 2 | | 1 | | | | 1 | | | |
| SEN | | | | 1 | 1 | | 2 | | 1 | | 1 | | | | 1 | | | | | | | | | |
| KLN | | | | 2½ | | | 2 | 1 | | 1 | 2 | | 3 | | | 1 | | 1 | | | | | 2 | |
| KSL | | 1 | | | | | | | 1 | | | 1 | 1 | | ½ | ½ | | 1 | 2 | 1 | | 1 | | |
| BAN | 2 | | | | 3 | | 5 | 1 | 2 | | | | | 1 | 4 | | | 1 | | | | | | |
| (SCW) SWN | | | | | | | | | | 1 | | | 1 | | | | | | | | | | | |
| HDG | | | | 4 | | | | | 3 | 1 | | 1 | | | | | | 1 | 2 | | | 2 | | |
| LDL | | | | 2 | | | 1 + WIDEBAND 24TI | | | | 1 | | | | 1 | | | 1 | | | | | | |
| LKF | 1 | | | 3 | 3 | | 2 | 1 | | ½ | 4 | | | 1 | | | 1 | 3 | | | | | | |
| ZBN | | | | | | | | | 1 | ½ | | | | | | | 1 | 1½ | | | | | | |
| ZWE | | | | | | | 1 | | | | | | | | 1 | 1 | | | | | | | | |
| PMS | | | | 4½ | | 1½ | | | 1 | 1 | 1 | | 1 | 1 | 3 | 1½ | | | | | | | | |
| KRE | | | | | | | | | | 2 | | | 1 | | | | | | | | | | | |
| WMS | | | | 2 | | | | | | 1 | | | | | | | | | | | | | | |
| LSY | | | | 1 | | | 1 | | | | | | | | | | | | | | | 2 | | |
| MHN | | | | | | | | | | 1 | | | 2 | | | | | | | | | | | |
| BDK | | | | 1 | | | | | 2 | | | | | | | | | | | 2 | | | | 2 |
| NOP | | | | | | | | | | | | | | | | | | | | | | | 2 | |

Figure 5-22. Connection Diagram for Central Germany

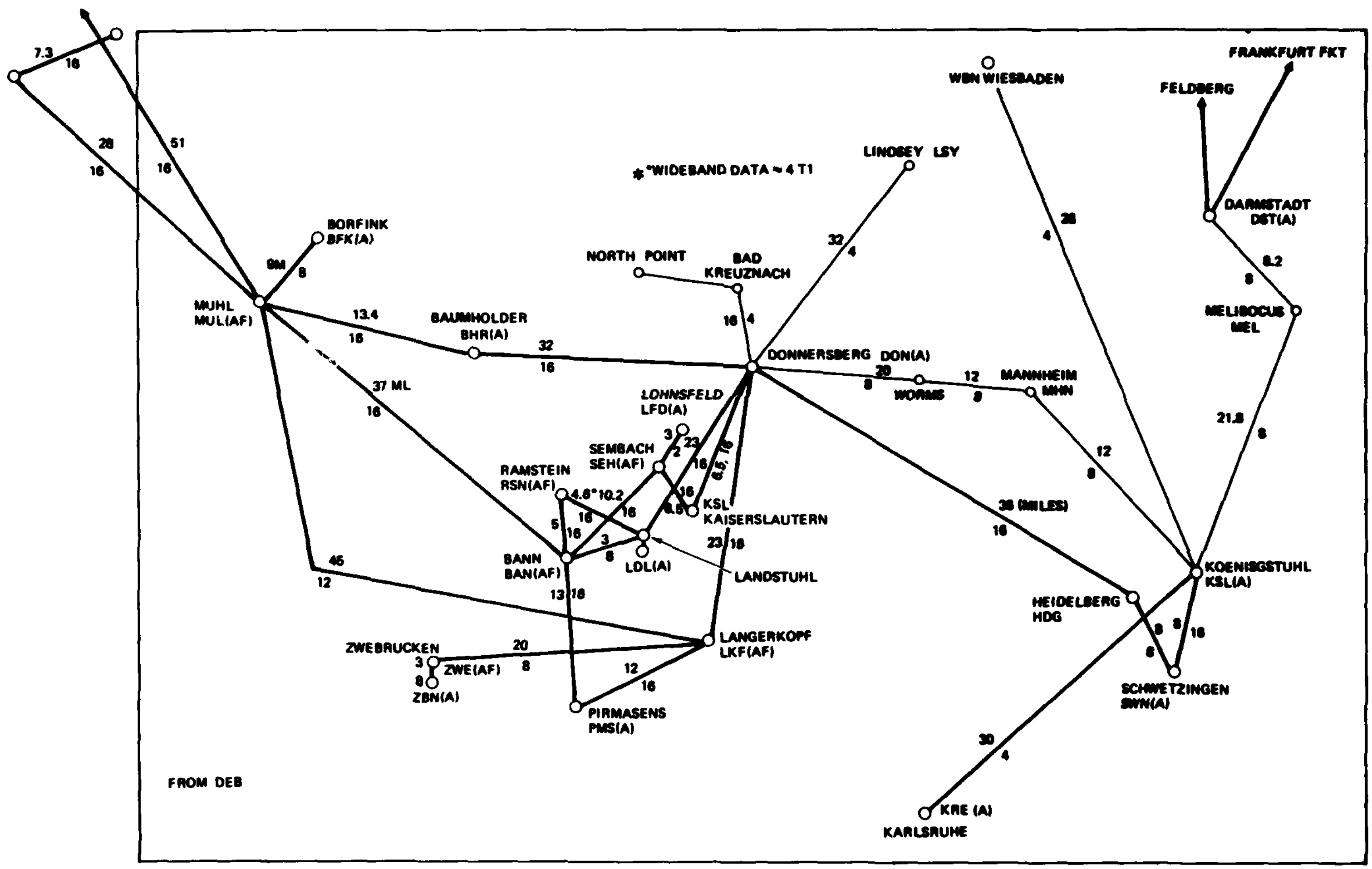
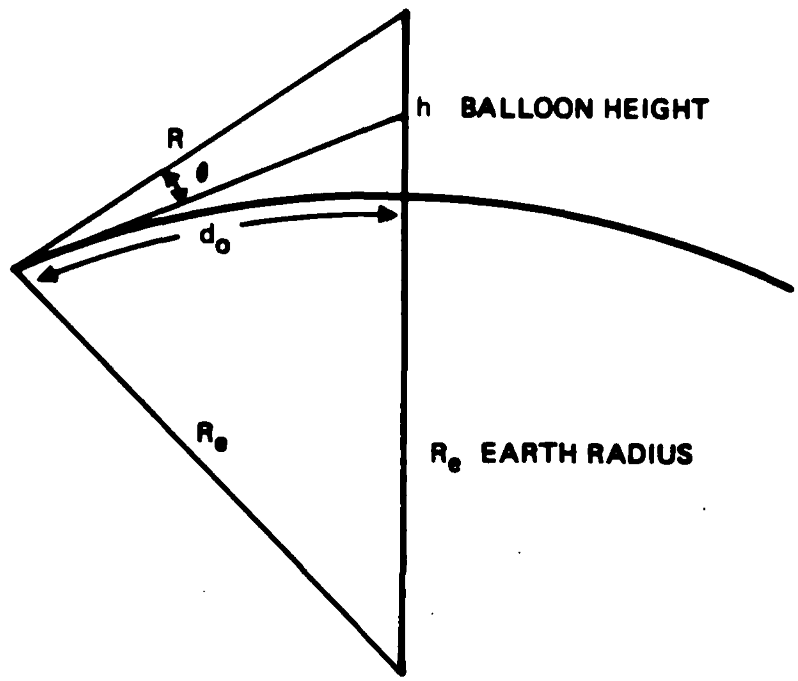



Figure 5-23. Geographic Distribution DCS Traffics in Central Germany

Variable rate for digital voice is also possible, as confirmed in ESIN study efforts to accomplish voice-rate control based on utilization of communication-channel capacity. This work showed that the incoming voice will be at lower data rate if a certain percentage of the multiplex capacity is occupied and that the data rate will be high if the demand of the channel is lower. Thus, a much smaller link capacity is able to handle a large number of voice channels at the expense of complex control and multiplexing schemes.

5.4.2.2 Transmission Network Alternative. Because of the high traffic density prevailing in the relatively small study area, an airborne relay center and switch platform could serve as a reasonable alternative means to interconnect all the communication nodes in the area. However, this airborne platform must be within line-of-sight of every communication node. As shown in Figure 5-24, if the altitude of the relay platform is at 15,000 feet, the line-of-sight earth coverage radius is about 75 km with a minimum antenna elevation angle of $3.75^{o}$.

A tethered balloon is a viable medium that can serve as an airborne platform capable of operating at the required altitude. A communications payload carried on the hull of the balloon receives the incoming message from any or all the stations within the area, the massage is processed onboard the balloon, and then is retransmitted to the designated receiving station. Some necessary controls can be performed either on the balloon or on the ground through a central control station. Power for the communications payload and command for necessary balloon control, such as maintenance of constant pressure and altitude and alignment along the wind direction, either can be generated onboard the balloon or can be carried up from the ground to the balloon through the tether cable. Using an airborne power generating system, on-the-air operating time of the balloon system would be limited by the fuel-carrying capacity of the balloon. A more detailed description of such a balloon is given in Appendix A to this report.




BALLOON HEIGHT $h = 4.57$ KM (15,000 FT)
LINE OF SIGHT RADIUS $d_o \approx 270$ KM
WITH ELEVATION ANGLE OF $\theta = 3.75^\circ$
$d_o \approx 75$ KM

WHICH IS ENOUGH TO COVER THE AREA OF INTEREST

Figure 5-24. Balloon Height and Area of Coverage

5.4.2.3 Multiple-Access Scheme for the Balloon Transponder. The tethered balloon can be considered as a low-altitude communications satellite. Therefore, all of the multiple-access schemes that are presently used and planned for future satellite communication systems also can be used for the balloon communication systems. The Frequency Division Multiple Access (FDMA) scheme and its Single-Channel-per Carrier Demand-Assigned Multiple-Access (SCPC-DAMA) technique are mature, fully-developed system concepts now in operation, and associated communications and control subsystems are relatively simple and are compatible with existing hardware. Also, many channels, each with a different center frequency, are contained within the total transponder bandwidth. However, because of potential intermodulation among the adjacent channels, the power amplifier is usually operated in linear mode with back-off.

On the other hand, the Time-Division-Multiple-Access (TDMA) scheme is not subject to the intermodulation problem because all the channels are operated within different time frames and the power amplifier therefore can operate at saturation with higher transmission efficiency. The latter method nevertheless requires complex timing and synchronization in addition to high-capacity buffers. However, oncoming advances in integrated-circuit technology not only will permit realization of high-speed digital hardware but also will ensure widespread application of TDMA communication systems in the near future.

The total data rate in the area of interest is about 160 Mbps provided the data rate of each voice channel is 64 kbps. If a proper coding scheme and a low-data-rate vocoder are used, the total data rate can be reduced by a factor of 4 or 8, for which case the transponder bandwidth will be reduced to within the 160-MHz to 40-MHz range. Also, the power available to the tethered balloon is adequate when compared with the limited power available on a satellite, which means that the FDMA system will be much more economical than other types of multiple access. Higher-modulation bandwith-efficient schemes also have been developed for the digital data transmission and it is therefore, possible to reduce the bandwidth even further from that required by the QPSK method (2 bits/Hz/sec).

5.4.2.4 Link Design of the Tethered-Balloon Communications System. Figure 5-25 shows a conceptual design of the balloon communication system. The aerostat electronic payload is the focal relay point for all the point-to-point communications, whereby multiple services are simultaneously provided over the entire ground-coverage area. Each communication node is assigned to a particular channel with an appropriate bandwidth based on the data-rate requirement of that particulare station. Outgoing signals of the ground transmitters will be received by the airborne antenna and processed by the signal processor, which will assemble all calls according to their destinations and direct each group of data to a particular down link carrier frequency. The total bandwidth of the up-and-down-links will be in the range from 40 to 160 MHz depending on modulation type and data-rate requirements. A block diagram of the onboard transponder is presented in Figure 5-26.

It also is possible to use the aerostat only as a relay and to leave the message-processing and switching functions to a centrally-located ground station, as shown in Figure 5-27. However, because this approach requires two uplink and two downlink frequencies the onboard processor is preferred.

The link budget was calculated on the basis of the following assumptions:

- Uplink central frequency: 7 GHz
- Downlink central frequency: 8 GHz
- Bandwith: 160 MHz/40 MHz
- Parametric Amplifier Noise Temperature: 500 $^{o}$K
- Maximum Link Distance: 70 km
- Onboard Antenna Gain: 3 dB
- Ground Antenna Size: 2-ft reflector.

Tables 5-18 and 5-19 identify the detailed communications-link calculations for the tethered balloon system.

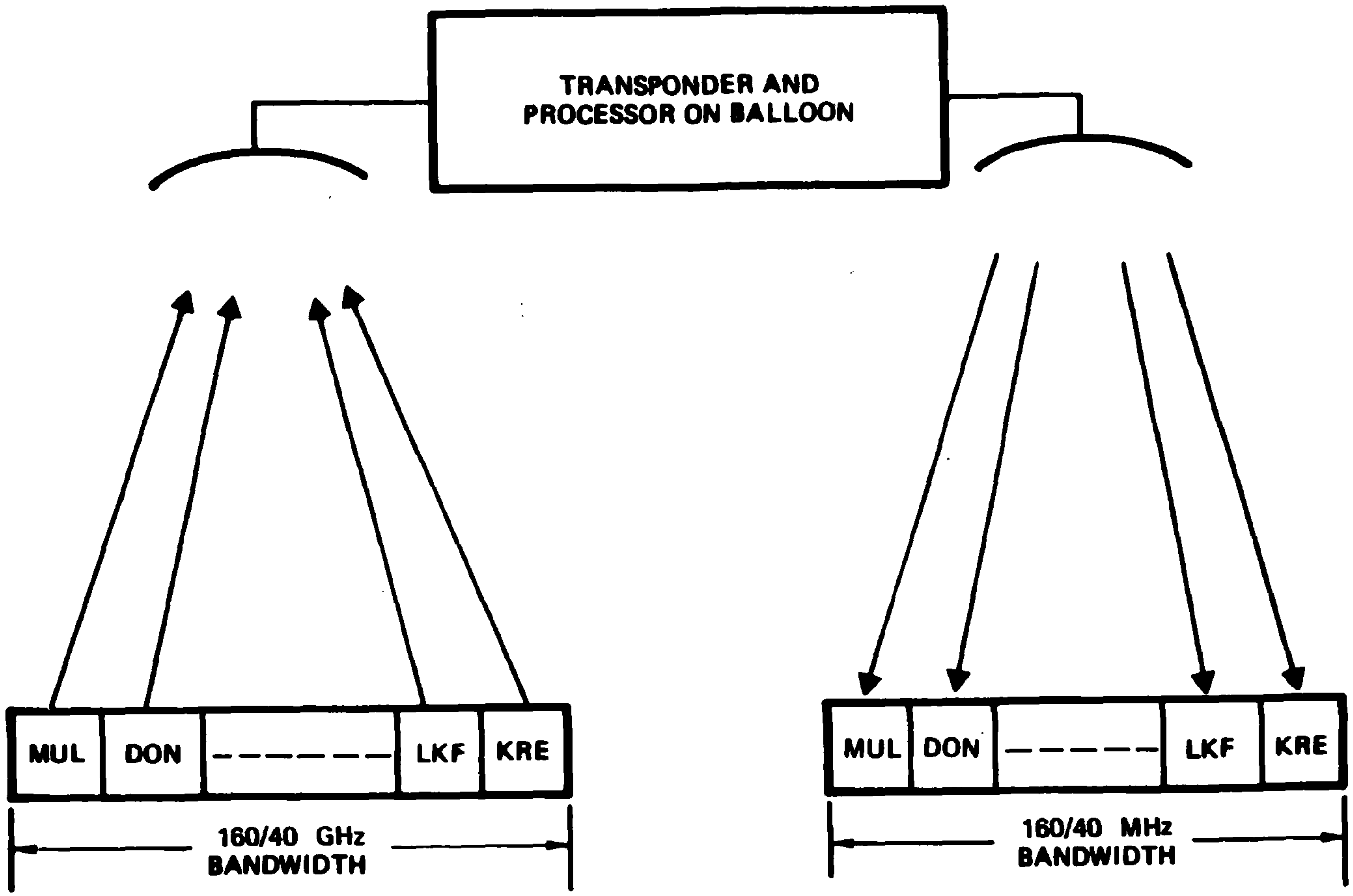



Figure 5-25. Conceptual Design of Balloon Communications System Showing Potential Channel Assignments for Users

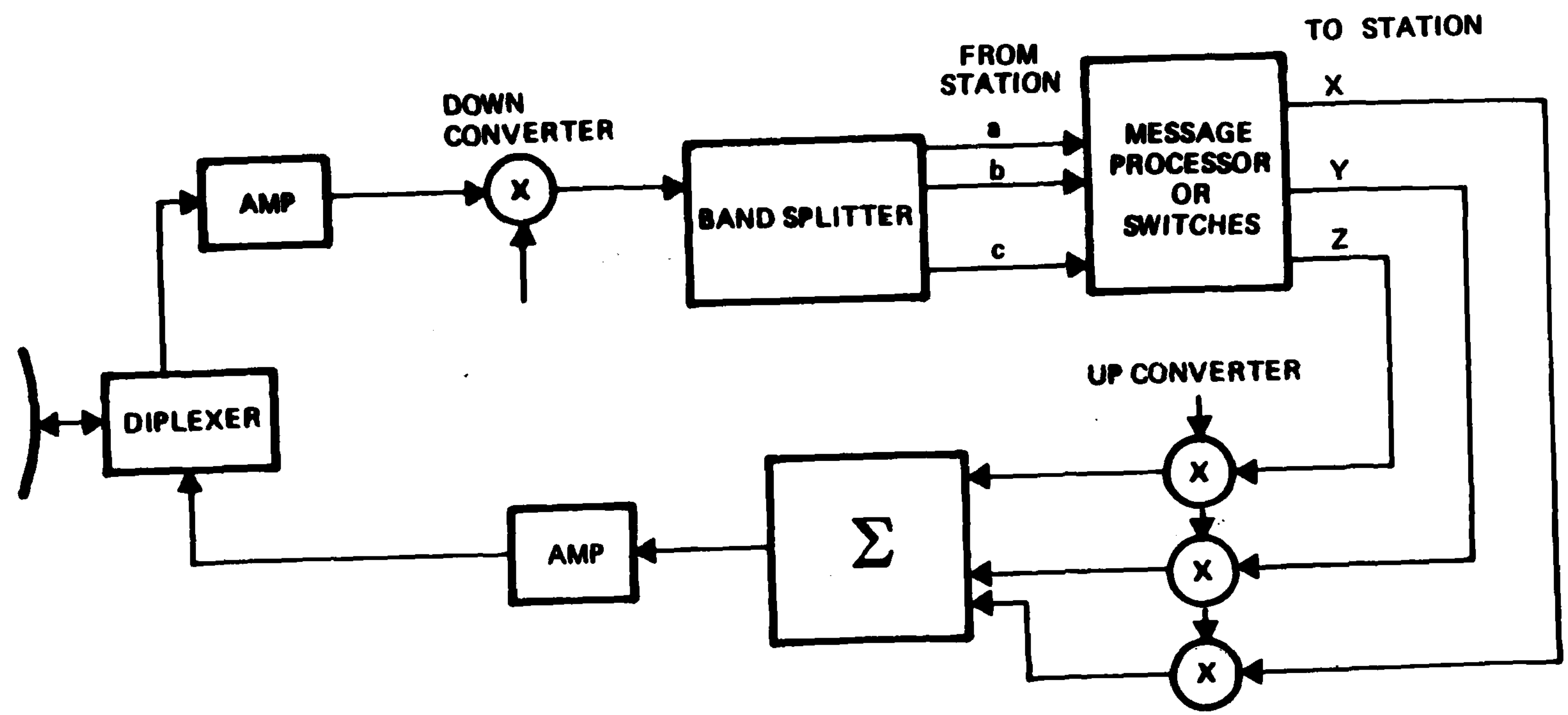



Figure 5-26. Block Diagram of Balloon Transponder

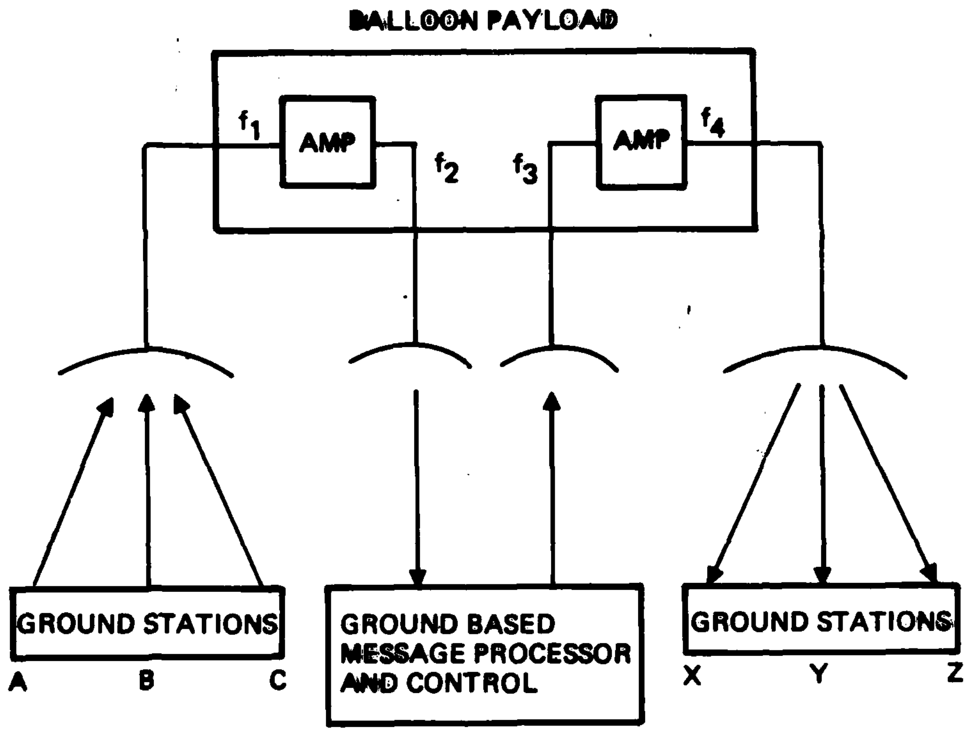



Figure 5-27. Concept of Ground-Controlled Balloon Relay Communications System

Table 5-18. Link Calculation for Balloon Transponder

| FREQUENCY GHz | DOWNLINK 8 | UPLINK 7 | REMARK |
|---|---|---|---|
| Transmitter Power, dB | 21.7 | 21.7 | 150 Watt |
| Transmitter Circuit Losses, dB | -2 | -2 | Waveguide, Switches, Diplexer |
| Transmitter Antenna Gain, db | 3 | 30.5 | 2 Ft. Reflector on Ground, Hemispheric on Balloon |
| Space Loss, dB | -147.4 | -146.3 | Distance at 70 km |
| Receiver Antenna Gain, dB | 31.6 | 3 | 2 Ft. Reflector on Ground, Hemispheric on Balloon |
| Receiver Front-End Loss, dB | -2 | -2 | Waveguide, Switches Diplexer |
| Receiver Input Power dB | -116.8 | -116.8 | |
| Receiver Noise Temp °k | 1000 | 1000 | Uncooled Paramp at Noise Temp = 500°k |
| Receiver Input Noise Power Density $N_o$,dB-Hz | -198.6 | -198.6 | |
| Receiver Signal to Noise Ratio $C/N_o$, dB | 103.5 | 103.5 | |

Table 5-19. Link Budget for Different Modulation Schemes

| Characteristics/Modulation | QPSK | 3-QPR | 7-QPR | 16-QASK |
|---|---|---|---|---|
| Bandwidth Efficiency (bit/Hz/Sec) | 2 | 2 | 4 | 4 |
| Theoretical $E_b/N_o$ at BER = $10^{-6}$, (dB) | 10.6 | 12.7 | 17.0 | 14.5 |
| Receiver Input $C/N^o$, (dB) | 103.5 | 103.5 | 103.5 | 103.5 |
| Minimum Bandwidth Requirement for 160 Mbps (MHz) | 80 | 80 | 40 | 40 |
| Maximum System Margin Available (dB) | 13.9 | 11.8 | 10.5 | 13.0 |

With 150-Watt transmitters used on the ground and onboard the aerostat, the QPSK transmission clearly offers the best system margin at 13.9 dB with BER = $10^{-6}$. The corresponding bandwidth for 80 MHz is wide enough to accommodate the data requirement of the area even if the voice data are at their highest possible data rate of 64 kbps. This modulation scheme is the most common digital communication type, and hardware and systems are readily available, which renders this system the most economical to implement in balloon or aerostat communication links.

5.4.2.5 Balloon Description. The aerostat system has been used both as a radar surveillance platform and as a communication relay station. It is designed to operate to an altitude of more then 12,000 ft with up to a 1000-lb payload. Size and capability depending on the application requirement. The following general descriptions identify important characteristics of the Sheldah balloon and associated systems, as discussed in detail in Appendix A to this report.

5.4.2.5.1 Performance. Maximum aerostat operating altitudes are a function of aerodynamic lift and drag, helium volume at altitude, total weight aloft, and environmental factors. Of all the environmental factors, wind exerts greatest effect on performance, with the dynamic pressure at the maximum operating wind velocity constituting the major load on the vehicle and tether. Also, the wind moves the vehicle slightly downwind. This effect is called "blowdown." Thus, if the vehicle is kept at the same altitude, increasing wind speeds cause greater blowdown, requiring more tether to be let out and resulting in more weight that must be carried. However, this added weight is more than offset by the aerodynamic lift generated by the vehicle. Perspective aerostat performance with respect to specific wind conditions around the world may be gained by examination of the wind profiles given in Figure 5-28, wherein maximum altitude and corresponding wind velocities for safe aerostat operation are indicated in comparison with 99-percentile wind velocities for various geographical locations. Thus it is seen that the aerostat can operate safely in most areas of the world.

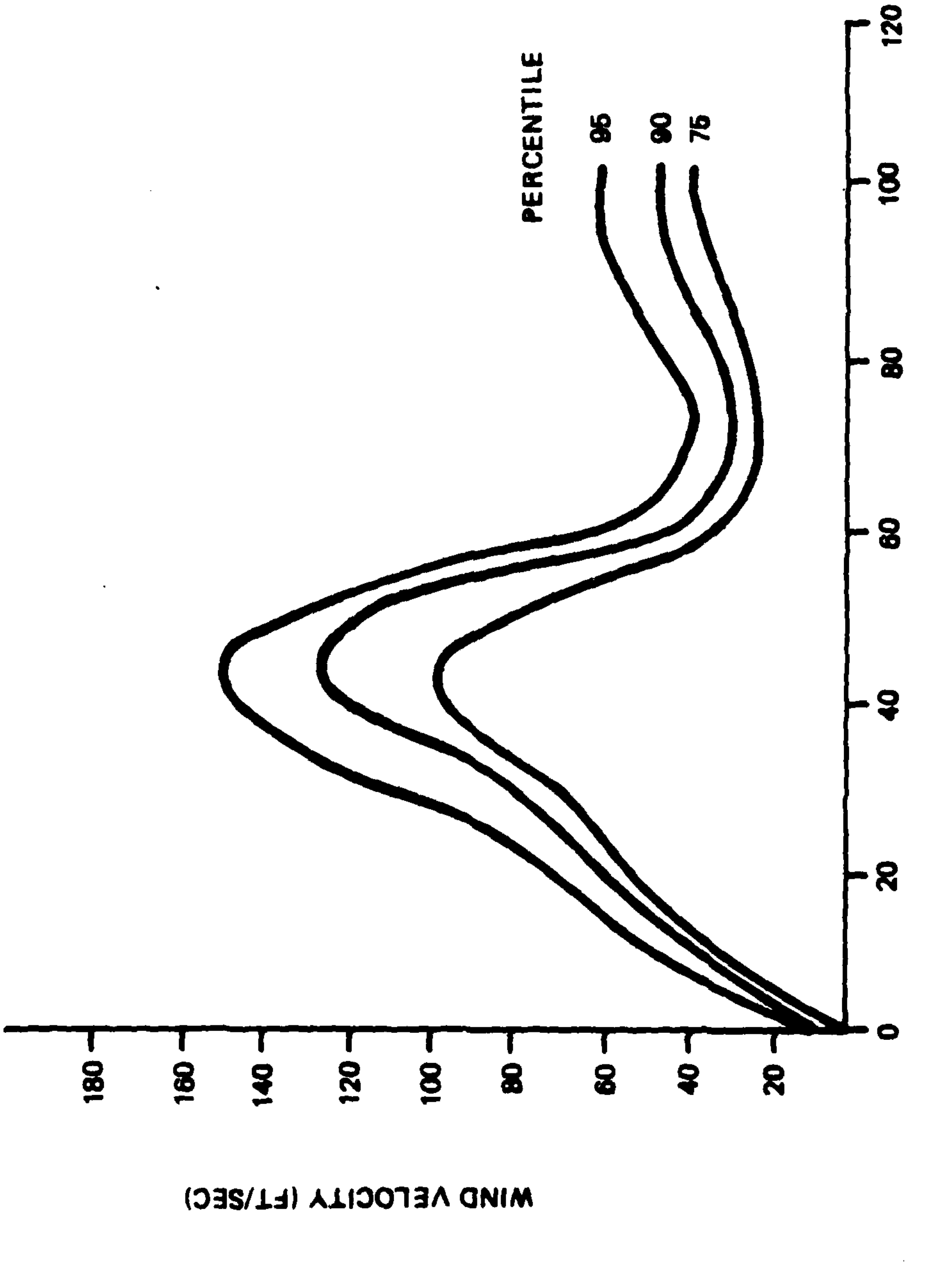



Figure 5-28. Wind Profile

Normal diurnal temperature changes can result in maximum temperature differences between the helium and the ambient air of about $40^{o}$ F, which produce an associated lift loss of up to 900 pounds in the most extreme case. This loss must be considered in payload weight selection if a constant day/night altitude is a requirement.

5.4.2.5.2 Materials. Present aerostat technology takes advantage of latest developments in materials engineering in production of the multilayer laminate material presently used for the aerostat hull. Laminate weight is 8.0 oz/sq/yd (280 $gm/m^2$) and consists of adhesive-bonded layers of TEDLAR and MYLAR films which in turn are bonded to DACRON cloth arranged in the manner shown in Appendix A to this report. This type of construction produces a very efficient material with a high strength-to-weight ratio. The TEDLAR film on the outside surface has excellent ultraviolet stability and weather resistance which protects the other components in the laminate, and in addition has good abrasion resistance. The two MYLAR films produce an efficient gas barrier with low values for helium permeability, so that lift loss for the entire aerostat is less than 25 pounds per day. The strong DACRON fabric has the ability to withstand loads induced by normal inflation, pressurization, hardware attachments, and inflight loading, while providing an appropriate design safety factor. The DACRON fabric also has good dimensional stability and imparts a high degree of tear resistance to the multilayer material.

Two of the most critical hull-material properties are biaxial tensile strength and tear strength. The requirement for tensile strength is 150 psi for a 14-day duration at $120^{o}$ F (including seals). The tear-strength requirement specifies that tears or defects in the material of up 3/4-in length can be sustained without propagating when biaxially loaded to 65 lb/in.

5.4.2.5.3 Tether Cable. Tether cables of Dacron, Aramid fiber, and steel have been used with and without encased power conductors. The size and weight of these cables is dependent upon aerostat size, maximum winds at the operational site, and electrical power requirements if power up the tether is required. At the present time tethers are abailable with capacity to deliver 20 kW of power to the aerostat. Tether weight ranges from 300 to 500 lb/1000 feet of cable depending upon the application. Cable life is entirely dependent upon the severity of the operation. Maintenance of a log which records the load history of the cable is recommended. Depending upon the cable, critiria should be established as to when a cable should be replaced on the basis of the loads it has sustained and the times it was subjected to those loads.

5.4.2.5.4 Airborne Power Generation. The standard airborne power unit consists of a Sachs-Wankel rotary engine directly coupled to a static brushless generator with a static voltage regulator. Each engine/generator power unit has a maximum power output of approxiately 5 kW at a flight altitude of 10,000 ft (3 km). The number of power units carried aloft therefore depends upon airborne electrical power requirements. All of the airborne power-generation equipment is mounted on an aluminum framework. Fuel consumption is noted in Appendix A as a function of engine loading for the Wankel engine at 10,000 ft (3 km) above sea level, and the consumption rate for a 5-kW load is slightly under 1.3 gallons (5 liters) per hour. Using an airborne power-generating system, mission times are limited by the fuel capacity of the aerostat.

5.4.2.5.5 Airborne Antenna. Antennas are located on the sides of the hull, inside the hull, in the fins, or along the trailing edges of the fins for various applications. The shape of the antenna and its particular function somewhat determine where and how it can be mounted. In the DCS III application the antenna must be capable of covering the whole area at the given frequency at X band. Its size and weight ultimately will depend on the final design, but the size is believed to be relatively small.

5.4.3 Alternative Design G-1. The second alternative communications-system design for central West Germany consists of the buried cable system described in Subsections 5.4.3.1 through 5.4.3.4.

5.4.3.1 Introduction. The hypothetical cable network that has been defined and proposed for the DCS locations in central West Germany is in the preliminary planning stage, with present work based on a selected map scale of 1:250,000 (Series M501, Edition 1, Sheets NM 32-7 (Saarbrucken) and NM 32-8 (Mannheim)). If greater detail is required subsequently a later-edition larger-scale map could be used. the number of VF circuits between two user endpoints was derived from the Digital European Backbone (DEB) Multiplex Plan. User requirements previously provided were disregarded because they were not consistent with the DEB plan and because the contracting officer directed use of the DEB plan as the baseline. The cable network nodes are located in proximity to the actual DCS station location. Local extensions from a network node to the precise DCS station location have not been considered, but generally would be less than one mile in length.

5.4.3.2 Primary Cable Network. A preliminary design for the cable network is shown in Figure 5-29. The network parallels the existing road network and routing is determined by taking the most direct route between two DCS node subscriber locations. Figure 5-29 also shows the logical connections of links required to support user needs, with the links individually identified by a unique letter or letters and citing road distance (to the nearest mile) between two nodes and also the number of VF channels. The same information is tabulated in Table 5-20, and VF channel-miles can be computed from this table if necessary. No spare channels or expansion capability have been added to channel requirements from the DEB plan.

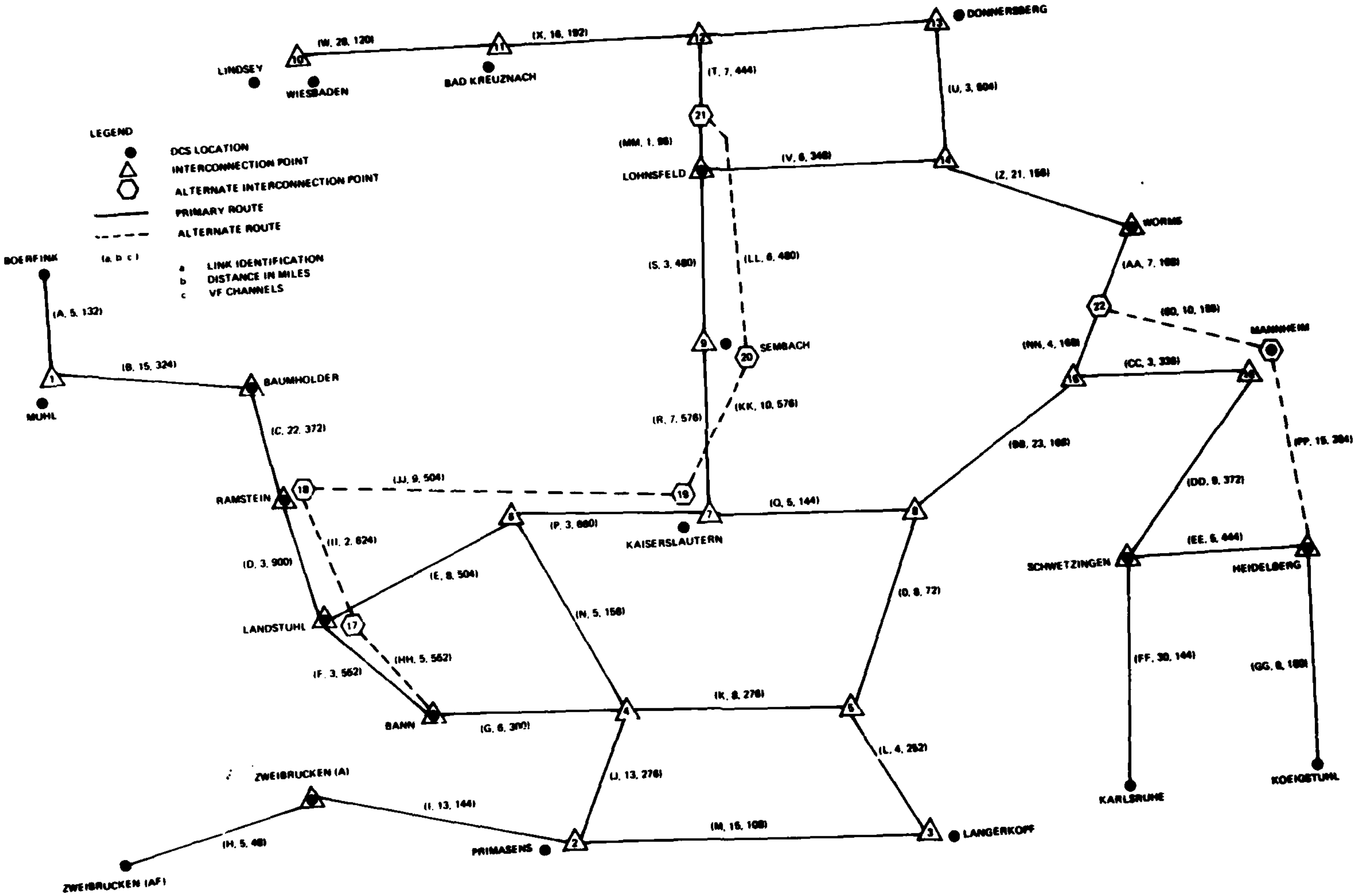



Figure 5-29. Primary and Alternate Cable Routes

Table 5-20. Cable Link Characteristics (Primary Routes)

| Link Identification | Location A | Location B | Distance (mi) | VF Channels |
|---|---|---|---|---|
| A | Boerfink | IP 1* | 5 | 132 |
| B | IP 1 | Baumholder | 15 | 324 |
| C | Baumholder | Ramstein | 22 | 372 |
| D | Ramstein | Lanstuhl | 3 | 900 |
| E | IP 6 | Landstuhl | 8 | 504 |
| F | Landstuhl | Bann | 3 | 552 |
| G | Bann | IP 4 | 6 | 300 |
| H | Zweibrucken (AF) | Zweibrucken (A) | 6 | 48 |
| I | Zweibrucken (A) | IP 2 | 13 | 144 |
| J | IP 2 | IP 4 | 13 | 276 |
| K | IP 4 | IP 5 | 8 | 276 |
| L | IP 5 | IP 3 | 4 | 252 |
| M | IP 2 | IP 3 | 15 | 108 |
| N | IP 4 | IP 6 | 5 | 156 |
| O | IP 5 | IP 8 | 8 | 72 |
| P | IP 6 | IP 7 | 3 | 660 |
| Q | IP 7 | IP 8 | 5 | 144 |
| R | IP 7 | IP 9 | 7 | 576 |
| S | IP 9 | Lohnsfeld | 3 | 480 |
| T | Lohnsfeld | IP 12 | 8 | 96 |
| U | IP 13 | IP 4 | 3 | 504 |
| V | Lohnsfeld | IP 14 | 6 | 348 |
| W | IP 10 | IP 11 | 28 | 120 |
| X | IP 11 | IP 12 | 16 | 192 |
| Y | IP 12 | IP 13 | 7 | 96 |
| Z | IP 14 | Worms | 21 | 156 |
| AA | Worms | IP 15 | 11 | 168 |
| BB | IP 8 | IP 15 | 23 | 168 |
| CC | IP 15 | IP 16 | 3 | 336 |
| DD | IP 16 | Schwetzingen | 9 | 372 |
| EE | Schwetzingen | Heidelberg | 5 | 444 |
| FF | Schwetzingen | Karlsruhe | 30 | 144 |
| GG | Heidelberg | Koenigstuhl | 8 | 180 |

*IP = Interconnection Point

Actual cable routes are shown in Figure 5-30, which is general in nature and wherein consideration was given to the type of cable system (twisted pair, fiber optics, carrier-cable, etc.). Also, because the design is hypothetical no consideration was given to existing outside plant facilities, right-of-ways, governmental restrictions, etc. The most direct routes were selected and no attempt was made to optimize the network.

5.4.3.3 Alternative Cable Network. The preliminary design for the primary network only included the routing for the minimum VF circuits, although some alternate routing could be provided by merely increasing the channel requirements in selected links. Nevertheless, some alternate routing may be advantageous, and these links are also shown in Figure 5-29. The number of VF circuits on the alternate routes provide an arbitrarily selected 100-percent backup. Only a minimum number of alternate links that appear to be most essential have been included. Alternative routes are shown in both Figures 5-29 and 5-30, and their characteristics are given in Table 5-21.

5.4.3.4 Conclusions. The cable network discussed above is hypothetical and has no relation to actual or planned DCS cable capabilities in central West Germany. Therefore, this network must be used as an alternative trasmission system for performance and/or cost comparison.

5.5 Candidate Alternative Transmission System for Turkey. This section describes the baseline system and two proposed alternative systems for Turkey.

5.5.1 Turkey Baseline Systems. The area of Turkey is much larger than that of central Germany, but the number of users is relatively smaller. Figure 5-31 shows the area of concern as well as various DCS sites within this region.

5.5.1.1 Existing System. A current system diagram based on DCS Five-Year Plan is shown in Figure 5-32, although details such as terminal equipment, transmitter power, and channel capacity were not available in the Five Year Plan. However, those parameters have been obtained from other sources.


Figure 5-30. Actual Cable Routes in Central Germany

Table 5-21. Cable Link Characteristics (Alternate Routes*)

| Link Identification | Location A | Location B | Distance (mi) | VF Channels |
|---|---|---|---|---|
| T | IP 21* | IP 12 | 7 | 444 |
| Y | IP 12 | IP 13 | 7 | 444 |
| AA | Worms | IP 22 | 7 | 168 |
| HH | Bann | IP 17 | 5 | 552 |
| II | IP 17 | IP 18 | 2 | 624 |
| JJ | IP 18 | IP 19 | 9 | 504 |
| KK | IP 19 | IP 20 | 10 | 576 |
| LL | IP 20 | IP 21 | 6 | 480 |
| MM | Lohnsfeld | IP 21 | 1 | 96 |
| NN | IP 15 | IP 22 | 4 | 168 |
| OO | IP 22 | Mannheim | 10 | 156 |
| PP | Mannheim | Heidelberg | 15 | 204 |

*Primary Routes not affected by alternate routing are not shown in this table.
**IP = Interconnection Point

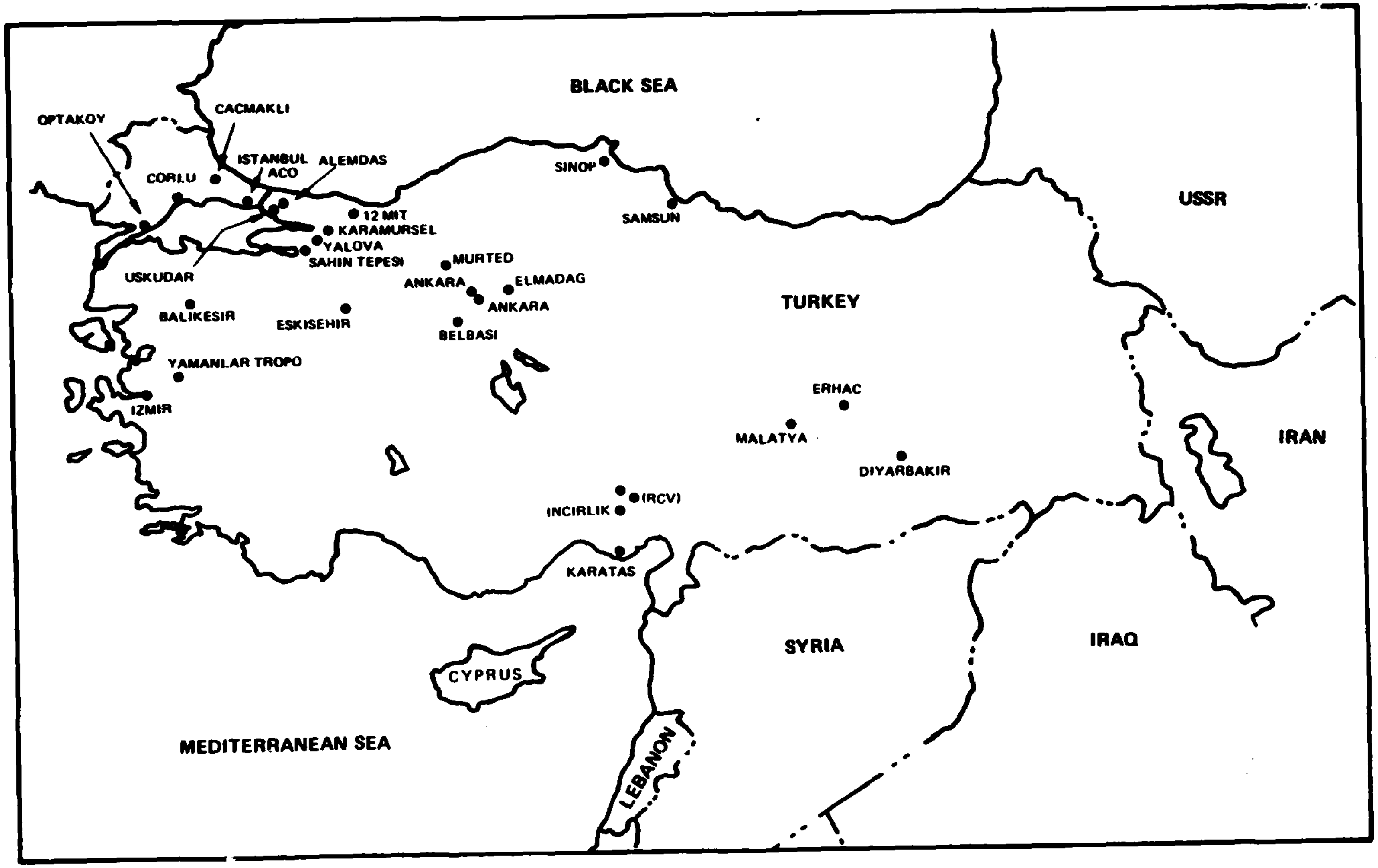



Figure 5-31. Mapa of Turkey with Some DCS Sites

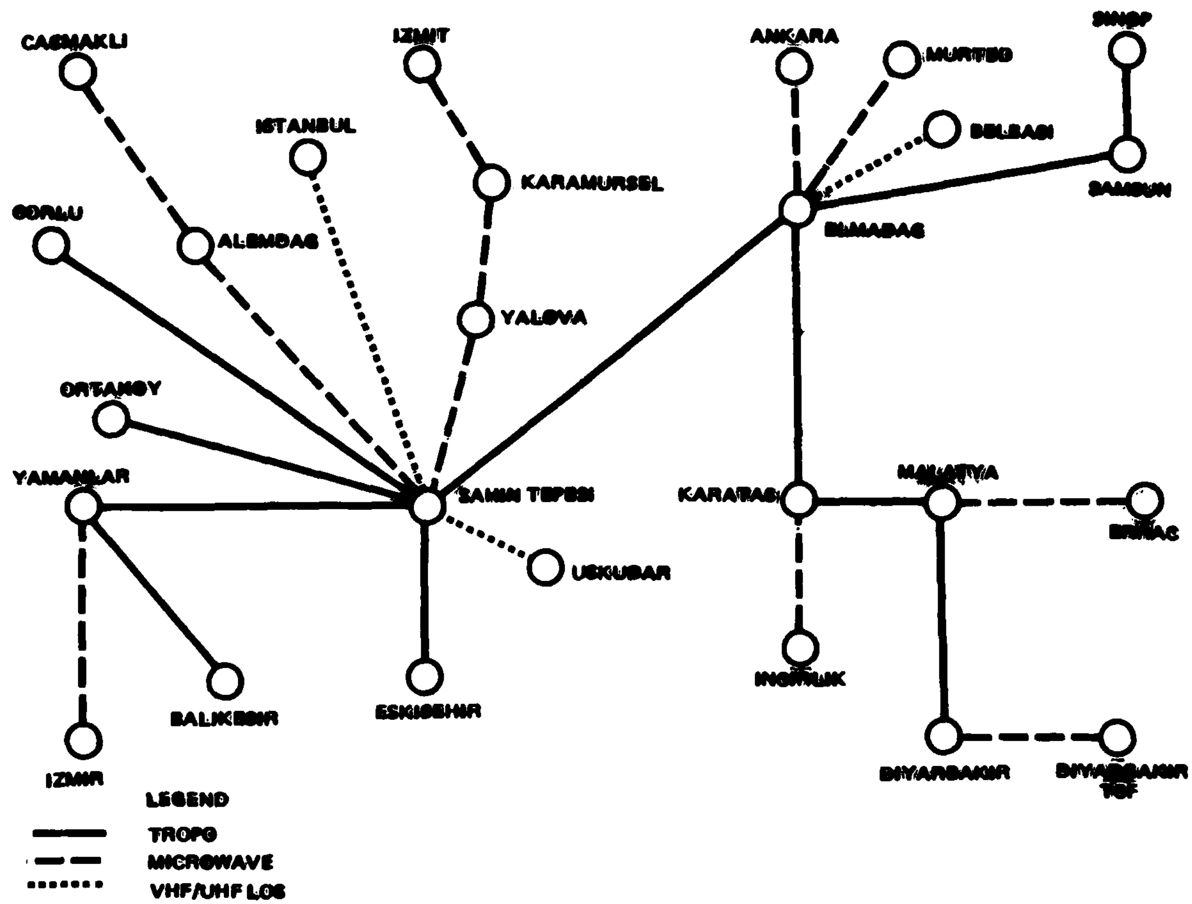



Figure 5-32. Existing Turkey DCS System

5.5.1.2 Proposed System. Current DCS plans are to upgrade the Turkey DCS during 1985-1990 in three phases. Information pertaining to Phases I and II are unclassified. With the exception of the link endpoints, the Phase III information is classified and will not be discussed in this report. A summary of proposed configuration is shown in Figures 5-33 and 5-34 respectively.

The proposed system will make use of digital modulation as opposed to the analog FDM-FM equipment presently in place. Although the analog system now in place is adequately designed and can accommodate required channel capacity without severe degradation. However, equipment in use is at least 20 years old and in some cases is antiquated in technology. For example, the parametric amplifiers now being used as low-noise front-ends should be superseded by modern solid-state. It can be assumed that the present radio equipment will be replaced. Intensive development programs are now underway to provide a new approach to digital modulation equipment for troposcatter links. The purpose of the new equipment is to overcome the degradation in the troposcatter medium due to intersymbol interference from path delays. Results to date are encouraging and support the assumption that these techniques will be available by 1985. Based on that premise it is reasonable to assume that the required digital channel capacity can be accommodated with RF power and antenna sizes shown for the present system but will require replacement of existing radio, MUX, and modulation equipment. In some cases antennas may be reused, but the waveg ues and feedhorns should be replaced. RF power and antenna sizes for new links must be determined as a function of terrain features.

5.5.1.3 DCS Connectivity. The DCS connectivity diagram shown in Figure 5-35 provides the same inforamtion as Table C of the Five year Plan with the two exceptions that an FDM radio link (IZMIT-GOLCUK) is shown on the connectivity diagram but not on the Five Year Plan and that a link (SAHIN TEPESI - USKUDAR) appears in the Five Year Plan but not on the connectivity diagram. The connectivity diagram also indicates which links are to be digital.

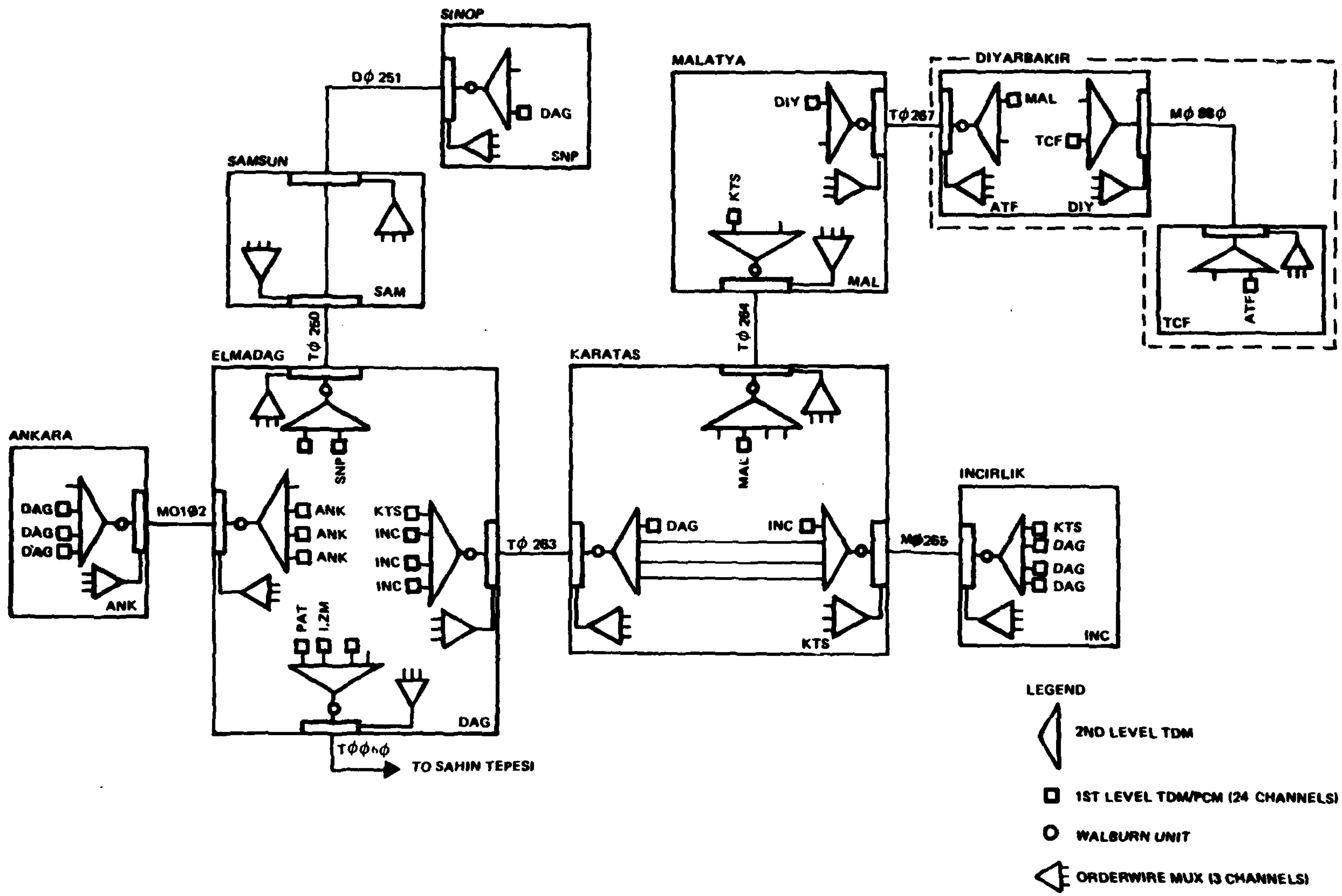



Figure 5-33. Proposed Multiplex Configuration, Phase I

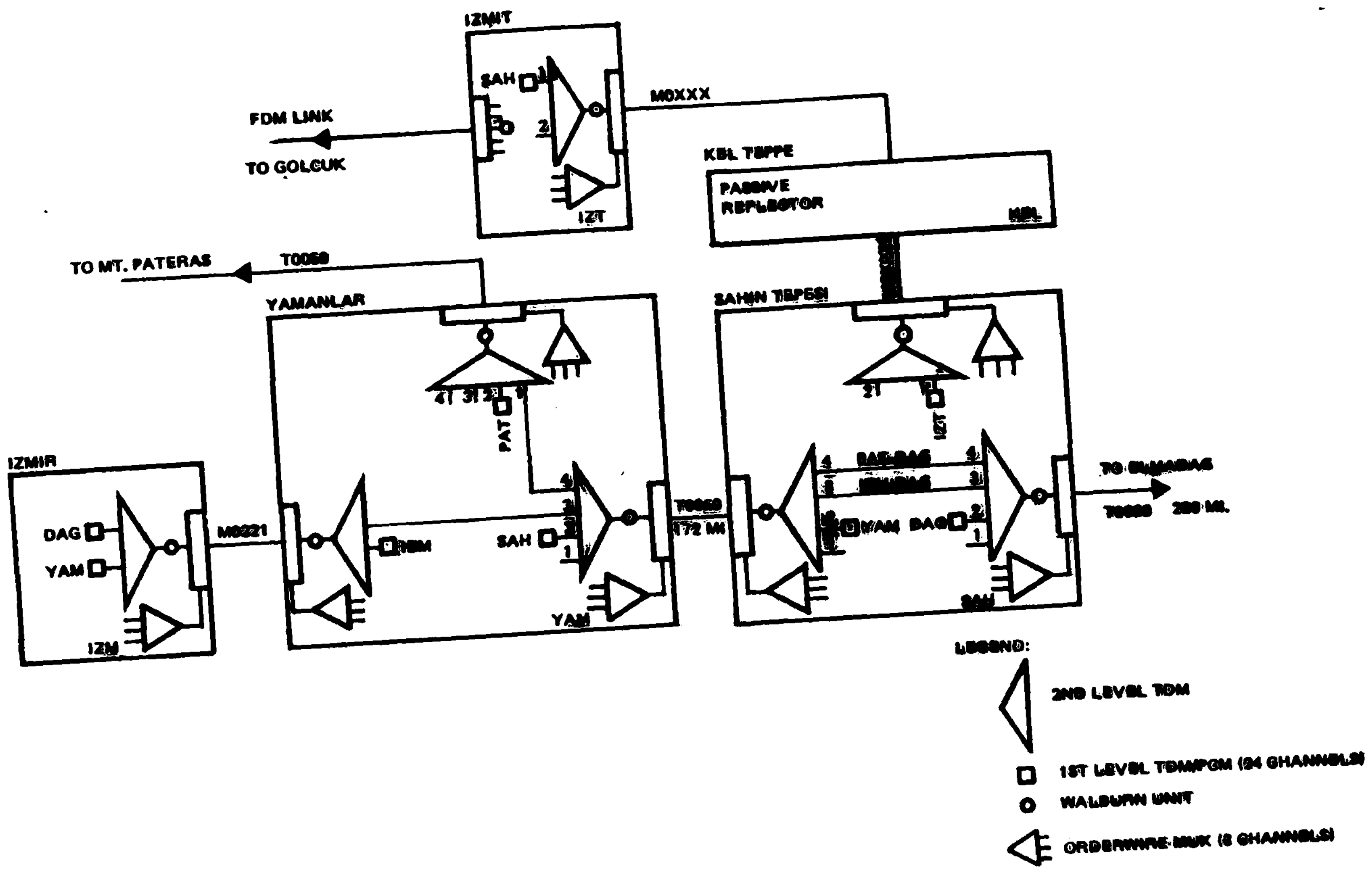



Figure 5-34. Proposed Mutiplex Configuration, Phase II

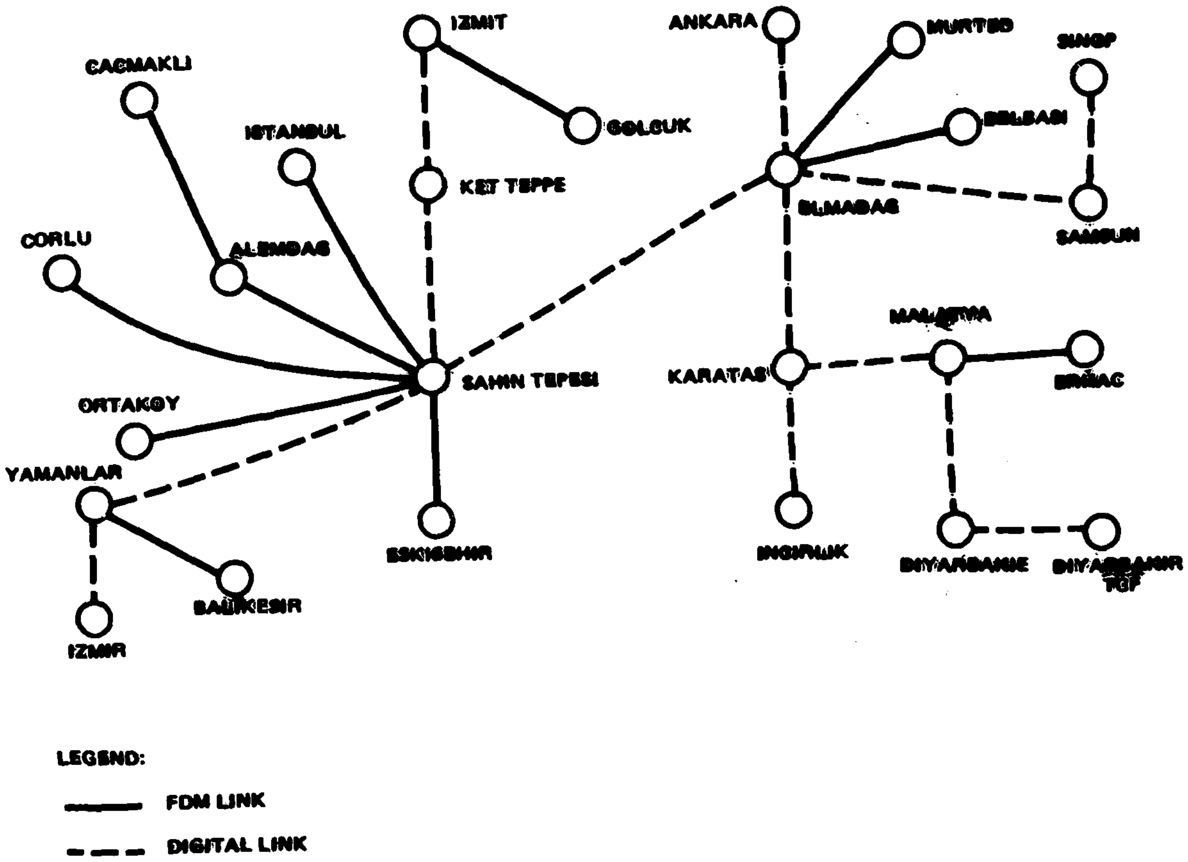



Figure 5-35. Projected 1985 Turkey DCS Connectivity

5.5.1.4 Conclusions. The information on the existing DCS is the best available at this time, although some of the information is old and may not reflect recent changes. However, the available information is adequate to establish or assume a baseline for Turkey, and it also may be assumed that no new sites (i.e., physical locations) will be constructed for DCS III but that equipment will be replaced or upgraded only at existing sites.

5.5.2 Alternative System Design T-1. An EHF satellite system proposed as an alternative communication system for Turkey could assume one of the following two configurations:

- Piggyback Package: Space segment is a separate package which rides on other military satellites, with power supply or other needed support provided by the mother satellite. Separate antenna may be needed to cover the Turkey area.

- Integrated Satellite: The 30/20-GHz EHF satellite is being considered for either the DSCS III upgraded or the DSCS III follow-on. Capacity described in the following Subsection 5.5.2.1 may be integrated into a satellite of the DCS III time frame.

5.5.2.1 Choice of Tranmission Alternative. The projected DCS network in Turkey shown in Figure 5-35 consists of a single-thread troposcatter network of communications nodes, each acting as a relay or the center of a star network of "local" communications links. The "local" communications may consist of other troposcatter links, some greater than 100 miles in length. In order to reduce vulnerability of critical terminals along the single thread due to natural or man-made outages DSCS III SATCOM terminals have also been provided or are planned for three of these nodes, but others remain vulnerable. Addition of more DSCS III terminals is possible but they are large, expensive, and more vulnerable to ECM because of their locations than most of the other SATCOM terminals in the DSCS III network. A previous study (Ref. 5-1) has shown that better ECM performance can be obtained at higher frequencies, but that at the highest frequencies technically feasible the links suffer high attenuation in bad weather.

This work also compared overall performance of a number of frequency bands and concluded that for ground terminals in temperate climates the optimum frequency bands are 30 GHz for the uplink and 20 Ghz for the downlink. Even in a non-jamming environments these bands offer the following advantages:

- Wide Bandwidth: Each of the bands provides a 1-GHz bandwidth which currently is virtually unused
- Narrow Beamwidth: A small antenna provides a narrow beamwidth (e.g., a 2-ft diameter antenna produces a beam about 1 degree wide at 30 GHz and 1-1/2 degrees wide at 20 GHz, which results in high gain for small aperture and higher discrimination which potentially provides many more longitude slots in the desirable but crowded synchronous equatorial orbit.

This transmission alternative under discussion therefore will reflect consideration of small terminals with antennas of less than 8-m diameter and transmitter power of 1 kW or less that use a 30-GHz uplink and a 20-GHz downlink to replace or supplement the major (long-haul) troposcatter links at Yamanlar, Izmir, Sahin Tepesi, Elmadag, Karatas, Incinlik, Samsun, Sinop, and Diyarbakir.

Figure 5-36 shows a simplified version of the currently planned DCS III network consisting of a mixture of troposcatter and microwave terminals and repeater stations backed up by three SATCOM terminals. SATCOM terminals usually handle critical and wideband data and some critical voice links (particularly secure conferencing), whereas the troposcatter channels carry analog voice channels, which are more tolerant than high-speed data channels of the fast deep fading of troposcatter links. The SATCOM terminals are also very useful (particularly, if located near the originator terminals) for handling traffic to out-of-region areas and thus avoid placing an excessive burden of carry-through traffic all the way through the region. For example, without the SATCOM terminal at Elmadag the troposcatter terminal traffic at Sahin Tepesi, Yamanlar, and Elmadate is increased 100 percent or more, and similar increases would occur through all the terminals and relays back to Italy and Germany.

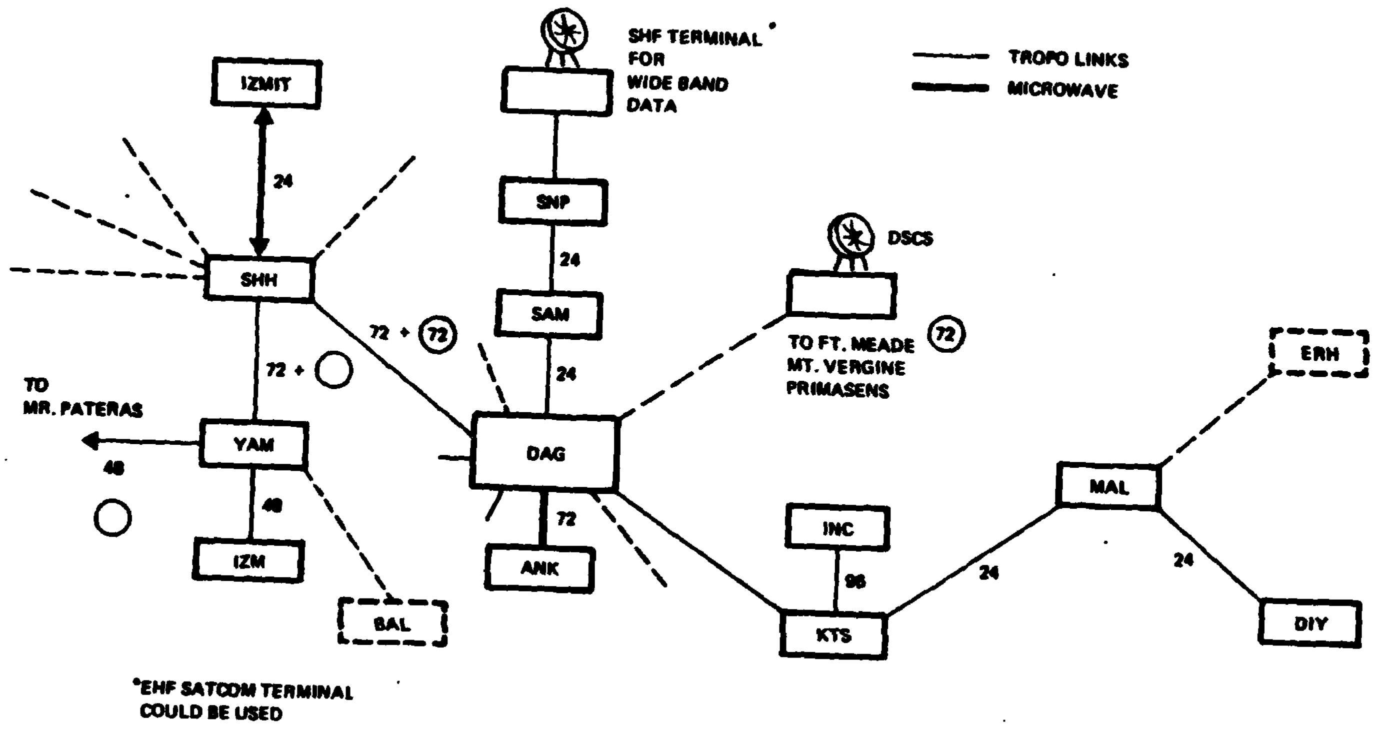



Figure 5-36. Simplified Turkey DCS Connectivity

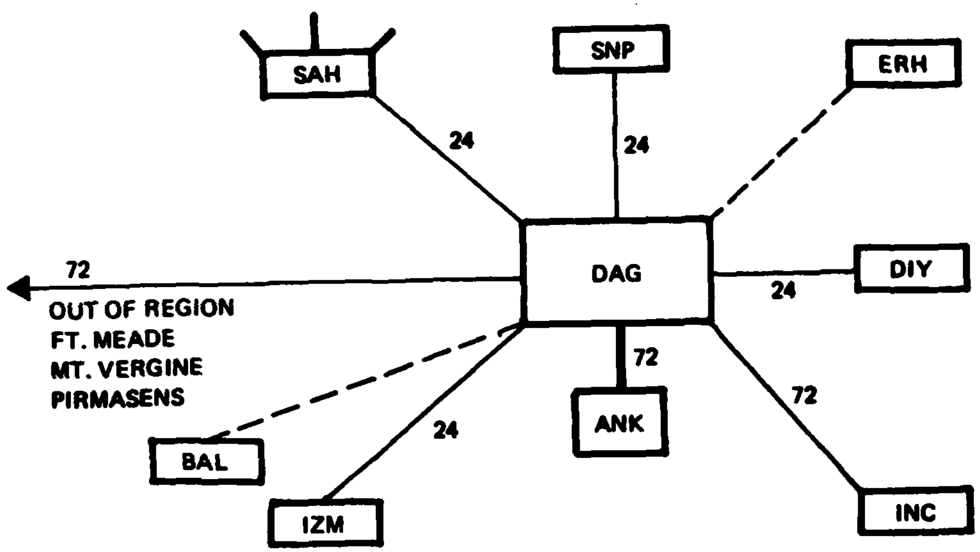
The alternative network thus would replace the major (backbone) troposcatter terminals at Izmir, Sahin Tepesi, Elmadag, Sinop, Incirlik, and Diyarbakir by 30/20-GHz SATCOM terminals, and also would eliminate the troposcatter sites at Yamanlar, Malatyar, Karatas, and Samsun. The microwave terminal at Erhac and the toposcatter terminal at Balikesir also would be replaced by a 30/10-GHz SATCOM terminals, while other Phase III tropo and microwave links to Sahin Tepesi and Elmadag would be retained as currently configured during Phase I and Phase II and possibly later, depending on the outcome of the Phase III evaluation.

Alternative connectivies are illustrated in Figure 5-37, which shows all of the new SATCOM terminals linked to the communications center at Elmadag via a 30/20-GHS transponder in the Atlantic DSCS III. As noted previously, Elmadag could handle the anti-jamming traffic in the various ways detailed subsequently Subsection 5.5.2.4.

Although the above alternative provides a number of advantages in a benign environment (and even is significantly better in a hostile environment) it also has some disadvantages which will be discussed below together with some mitigating factors, as elaborated in following Subsections 5.5.2.2 through 5.5.2.6.

### 5.5.2.2 Technical Maturity

A major advantage of the SHF SATCOM system is the maturity of currently available related technology. On the other hand, EHF SATCOM technology development is increasing very rapidly at the present time to a point where adequate flight-qualified equipment is expected to become available in the next few years. This topic discussed in more detail in Appendix A to this report, where it is concluded that the EHF SATCOM technology available in the time frame of DCS III will be capable of providing the needed performance.




NOTE: TROPO STATIONS AT YAMALA, MALATYA, SAMSUN AND KARATAS ELIMINATED. ADD TERMINALS AT BALIKESIR AND ERHAC.

Figure 5-37. Proposed EHF Transmission System Connectivity

### 5.5.2.3 Atmospheric Attenuation

Figures 5-38 and 5-39 illustrate the attenuation of a satellite/earth link as a function of frequency and weather conditions for a given temperature zone and continental summer climate and also the corrresponding increase in antenna noise temperature for an elevation angle of 30 degrees.

A considerable attenuation of 8 dB is indicated for a precipitation rate of 5 mm/hr, which may occur for about 0.5 percent of the year in the vicinity of Washington, D.C. The attenuation is significantly less during the other seasons due to lower freezing-level height and the smaller amount of water vapor per cubic meter in the atmosphere (Ref. 5-1). It is also much less in some other regions of the USA and in their counterparts in other countries.

Turkey has two climate zones, both more favorable than that evaluated in Figure 5-38. The coastal regions incuding terminal locations such as Izmir, Sahin Tepesi, Sinop, and Incirlik have a Mediterranean subtropical climate with virtually no rain in the summer. The climate of Elmadag, Diryarbakir, and Erhac is similar to that of Albuquerque, which is generally dry but can have rain during any month with a maximum precipitation in the late Spring or early Summer season. Monthly or seasonal precipitation statistics are needed to evaluate the seasonal attenuations, which vary significantly from season to season. Monthly rain statistics have been obtained for Albuquerque and Tel Aviv (the latter slightly modified using annual data from Adana, Turkey) to obtain the appropriate seasonal attenuation probabilities as shown in Table 5-22 for an elevation angle of 30 degrees (Ref. 5-2). These values are greater at locations where the elevation angle to the satellite is less than 30 degrees, but even at Diyarbakir (21 degrees) the 20-GHz attenuation for 99.5 percent of the time is less than 6.7 dB, as indicated in Table 5-23. However, the total effect due to the high antenna gain derived from 30-GHz and 20-GHz antennas and to the comparatively dry climate of Turkey results in similar performance for the same spacecraft and terminal equipment at either 7.6 GHz or 20 GHz under moderate rain conditions as well as better performance at 20 GHz for fine or cloudy weather, which is statistically more important. Thus, although atmospheric attenuation is greater, results are better at the higher frequency most of the time and only slightly worse for less than 0.5 percent of the time.

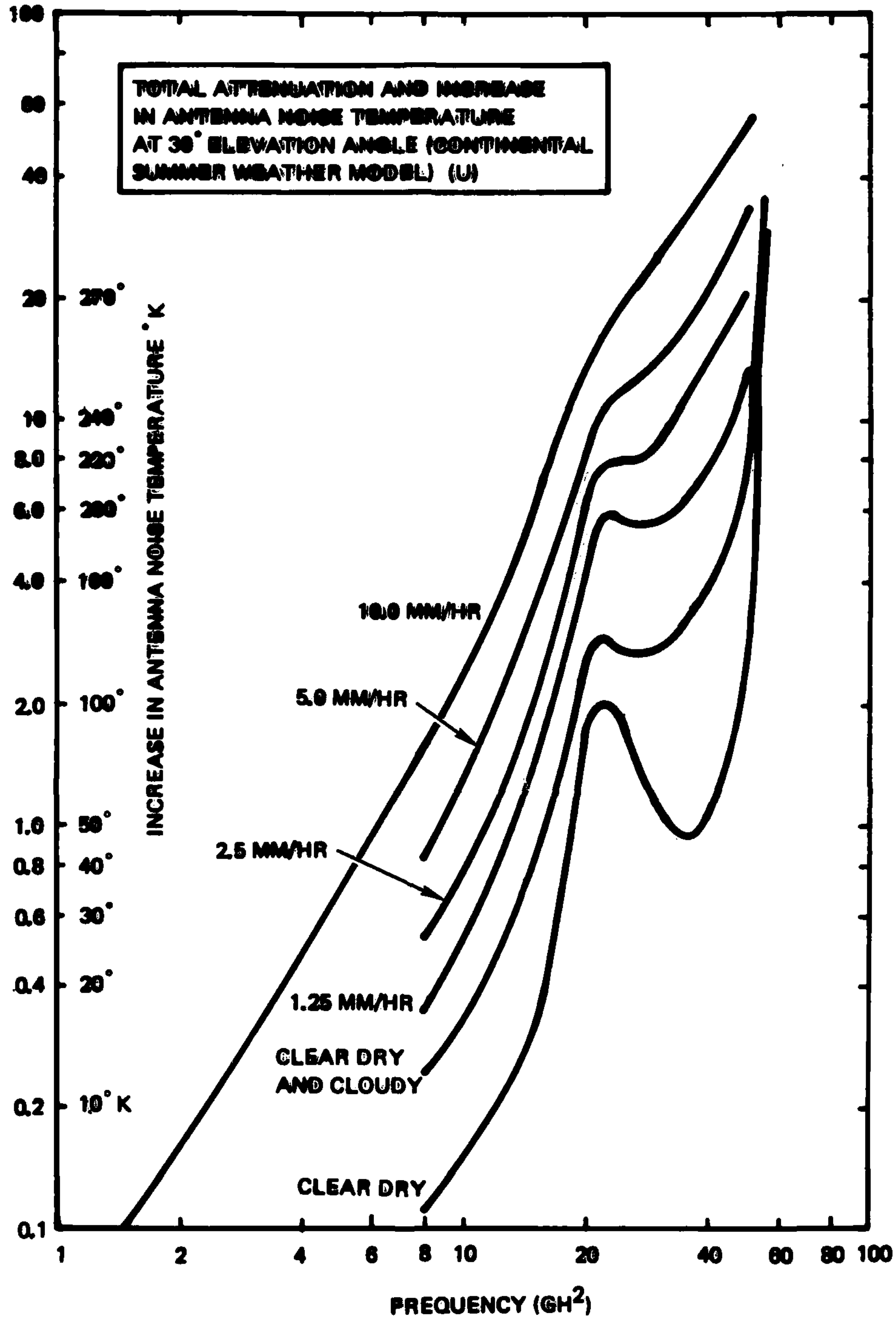



Figure 5-38. Total Attenuation and Increase in Antenna Noise Temperature at 30° Elevation Angle, Continental Summer Weather Model

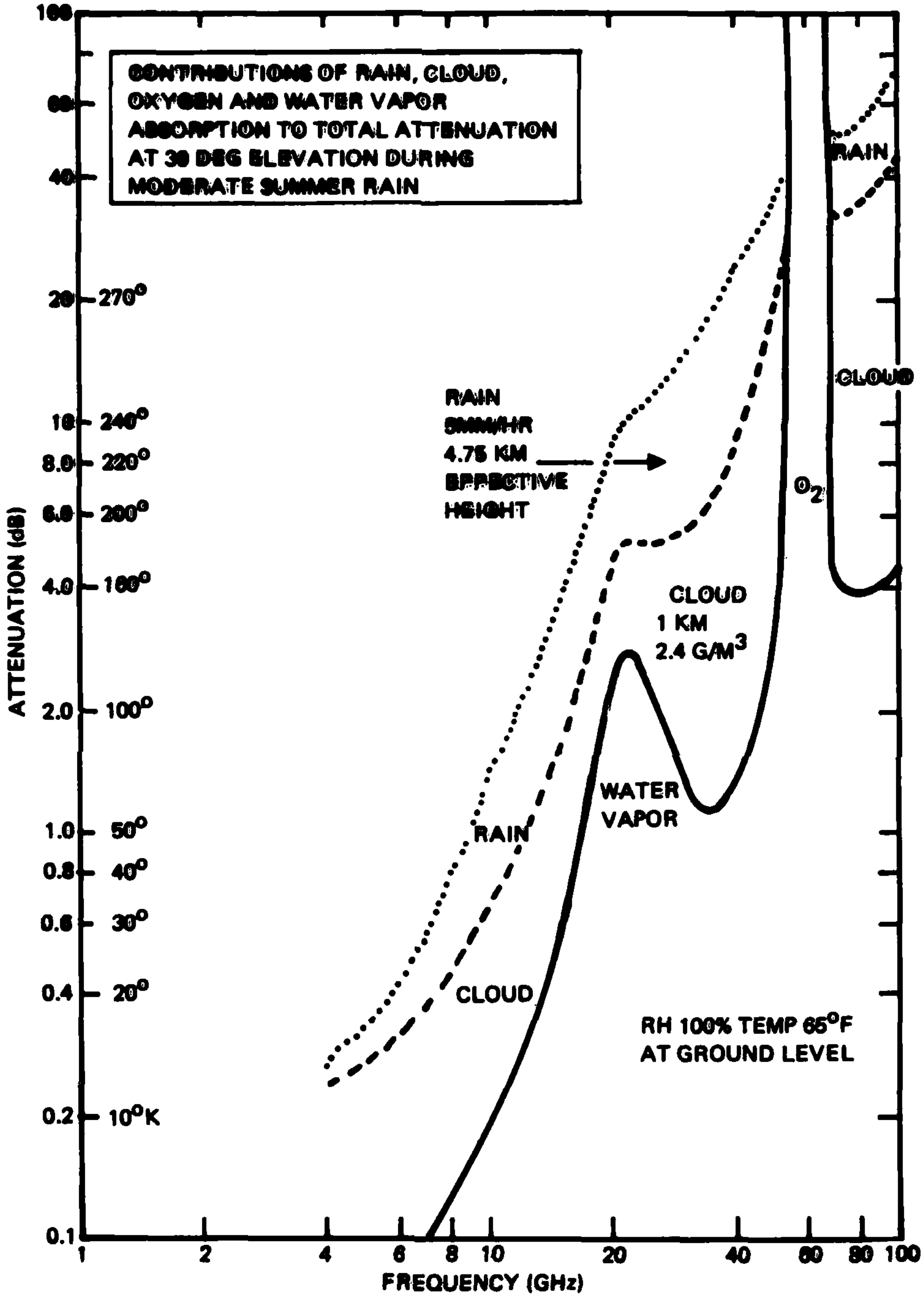



Figure 5-39. Contributions of Rain, Cloud, Oxygen, and Water Vapor Absorption to Total Attenuation at 30° Elevation During Moderate Summer Rain

Table 5-22. SATCOM Attenuation at 30° Elevation in Representative Climate Zones as a Function of Season

| RAIN RATE MM/HR | WINTER | | | SPRING AND FALL | | | SUMMER | | |
|---|---|---|---|---|---|---|---|---|---|
| | HOURS | ATTENUATION (dB) | | HOURS | ATTENUATION (dB) | | HOURS | ATTENUATION (dB) | |
| | | 30GHz | 20GHz | | 30GHz | 20GHz | | 30GHz | 20GHz |
| ELMADAG TURKEY (NOTE 1) | | | | | | | | | |
| 1.25 | 7.8 | 2.8 | 1.8 | 22 | 4.1 | 3.3 | 17 | 5.7 | 4.8 |
| 2.5 | 2.8 | 4.5 | 2.6 | 13.2 | 6.3 | 4.4 | 9.5 | 9.1 | 6.4 |
| 5.0 | – | 6.7 | 3.7 | 4.9 | 9.7 | 6.0 | 5.0 | 14.7 | 9.0 |
| 10.0 | – | 10.0 | 5.6 | 1.5 | 15.3 | 8.8 | 2.2 | 25 | 14.0 |
| INCIRLIK TURKEY (NOTE 2) | | | | | | | | | |
| 1.25 | 47.2 | 2.8 | 1.8 | 69 | 4.1 | 3.3 | NO SIGNIFICANT PRECIPITATION | – | – |
| 2.5 | 21.0 | 4.5 | 2.6 | 28.3 | 6.3 | 4.4 | | – | – |
| 15.0 | 5.6 | 6.7 | 3.7 | 7.8 | 9.7 | 6.0 | | – | – |
| 10.0 | 0.5 | 10.0 | 5.6 | 0.89 | 15.3 | 8.8 | | – | – |

NOTE 1 = FROM MONTHLY STATISTICS FROM ALBUQUERQUE, NEW MEXICO

NOTE 2 = FROM MONTHLY STATISTICS FROM TEL AVIV MODIFIED BY ANNUAL DATA FROM ADANA, TURKEY

Table 5-23. Beam Position and Weather Factors

| TERMINAL LOCATION | EL ANGLE | ANTENNA BEAM POSITION LOSS (dB) | | WEATHER LOSS IN dB | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | RAIN(1) | | DRIZZLE(2) | | CLOUD | |
| | | 30GHz | 20GHz | 30GHz | 20GHz | 30GHz | 20GHz | 30GHz | 20GHz |
| SAHIN TEPESI | 28° | 2 | 1 | 6.9 | 4.7 | 3.3 | 3.0 | 2.2 | 1.6 |
| SINOP | 24° | 2 | 1 | 8.0 | 5.4 | 3.8 | 3.5 | 2.5 | 1.8 |
| INCIRLIK | 24° | 2 | 1 | 8.0 | 5.4 | 3.8 | 3.5 | 2.5 | 1.8 |
| IZMIR | 29° | 2 | 1 | 6.7 | 4.5 | 3.2 | 2.9 | 2.1 | 1.5 |
| DIYAR BAKIR* | 21° | 2 | 1 | 8.8 | 6.7 | 5.2 | 5.2 | 3.5 | 3.1 |
| ELMAGDAG* | 28° | 1 | 1/2 | 6.7 | 5.1 | 4.0 | 4.0 | 2.7 | 2.4 |

*THESE LOCATIONS HAVE CONTINENTAL CLIMATE

(1) LESS THAN THIS VALUE 99.5 PERCENT OF TIME

(2) LESS THAN THIS VALUE 95 PERCENT TO 99 PERCENT OF TIME

5.5.2.4 Narrow Beamwidth. In the ECCM case the narrow beamwidth possible at EHF is a distinct advantage, although under benign conditions a narrow bandwidth may be a disadvantage because of possible limitation of coverage available and/or because of unfeasibility due to limitation of point accuracy of the space platform. However, assuming current technology, an open-loop pointing accuracy of between 0.1 and 0.2 degrees is attainable, so that a beamwidth of less than one degree is feasible. Figure 5-40 shows coverage of Turkey with a single 2-ft diameter antenna (assumed on a DSCS II spacecraft over the Atlantic Ocean) which produces a 1.1-degree beam at 30 GHz and a 1.7-degree beam at 20 GHz. These angles are adequate for uplinks and downlinks although there are significant differences between station locations which should be taken into account individually. This factor of antenna beam position loss also is reflected in Table 5-23 together with the angle of elevation to the satellite and the corresponding loss due to atmospheric attenuation. The antenna size chosen represents a good compromise between antenna gain and coverage (in terms of low antenna beam position loss) for all Turkish terminal locations using a transponder on a DSCS III spacecraft over the Atlantic OCean. Also, Turkey is well located to take advantage of a transponder on the Indian Ocean DSCS III. In fact, higher elevation angles can be obtained compared with the Atlantic DSCS III transponder, although two antennas of the same size and representing a potential loss of 3 dB if shared by the same transponder are required to obtain adequate coverage, as shown in Figure 5-41. Table 5-23 also shows that the reduced bad-weather loss due to higher angle of elevation largely offsets the potential loss caused by the greater angular coverage that is required by the different satellite/terminal geometries of the Indian Ocean spacecraft.

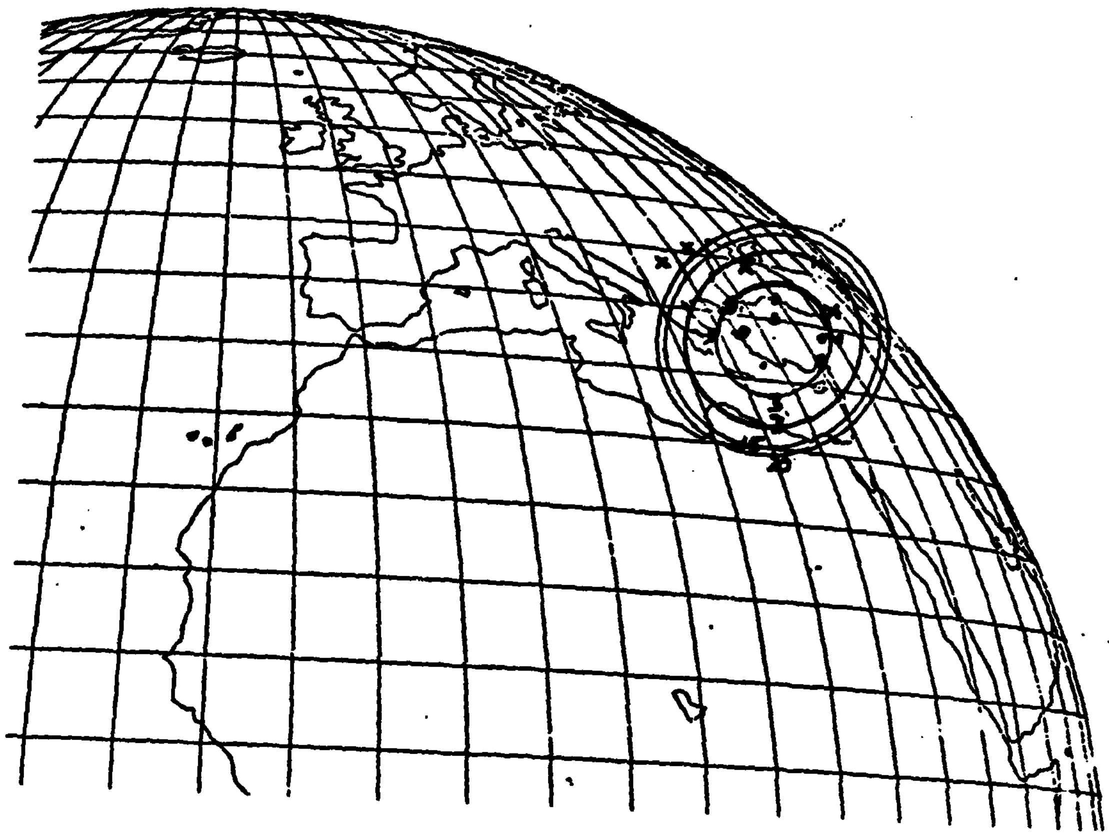


Figure 5-40. Beam Coverage

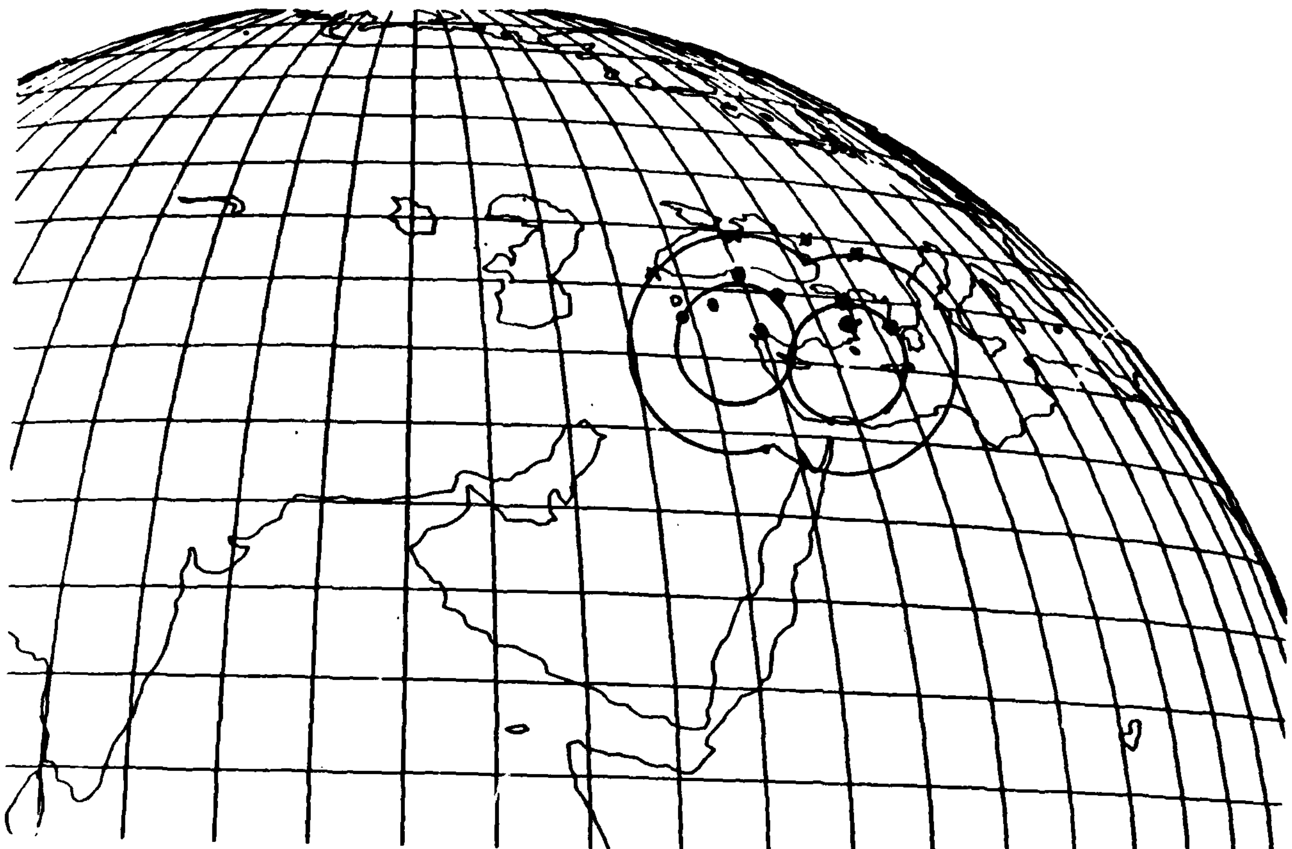


Figure 5-41. 2-Antenna-Beam Coverage for Turkey

The conceptual antenna patterns indicated in Figure 5-41 may not be feasible in practice with a single carrier frequency because the 3-dB contours of adjacent beams with the same frequency (or time slot) should not overlap. Two carrier frequencies (or time slots in a TDMA system), or as an alternative separate elliptical uplink and downlink antennas may be necessary. The configuration implied by Figure 5-41 consequently would be feasible only for the 30-GHz uplink but not for the 20-GHz downlink. Although some antenna development may be required, it appears that roughly the same performance can be obtained using a transponder on either the Atlantic or the Indian Ocean satellite as a host vehicle.

5.5.2.5 System Performance. Subsection 5.5.2.4 demonstrates that although the 30-GHz and 20-GHz bands suffer same disadvantages due to atmospheric loss in bad weather, such losses are reasonable due to the favorable location of Turkey with respect to either of the two available DSCS III positions in the geosynchronous orbits. Moreover, the higher frequencies enable use of a high-gain beam from a comparatively small 2-ft antenna. The uplink and downlink power budget of Table 5-24 show that a small transportable terminal can trasmit or receive up to a 46-Mbps data rate with an availability of better than 99 percent at the most disadvantaged location, such as for example, at Diyarbakir, which is characterized by both the worst beam position and the most severe atmospheric attenuation losses. This represents the total network capability because the downlink is the dominant factor (as can be seen by the very small 0.4- to 0.8-dB loss due to degradation of the downlink by uplink losses) and the downlink power is shared by all of ther terminals.

The network can handle 30 T1 channels (46 Mbps) in bad weather and over twice as many most of the time. Estimated requirements of the channels shown in Figure 5-37, except the channels indicated by dashed lines, are 240 voice circuits, or 3.840 Mbps at 16 Kbps per circuit (15.360-Mbps voice data rate). Because very few (or no) 64-kbps circuits are anticipated it is apparent that a very significant margin is available for other services provided. This could take the form of wideband data [illegible] of the stations or of low-data-rate voice circuits for a number of [illegible] locations, some of which currently are entirely dependent on [illegible] for critical communication.

Table 5-24. Uplink and Downlink Power Budgets

| PARAMETER | RAIN < 0.5%/YEAR | | DRIZZLE (0.25m) | | CLOUD | |
|---|---|---|---|---|---|---|
| | UP | DOWN | UP | DOWN | UP | DOWN |
| FREQUENCY | 30.5 | 20.7 | 30.5 | 20.7 | 30.5 | 20.7 |
| S/C ANTENNA GAIN (BORESIGHT) dB | – | 39.5 | – | 39.5 | – | 39.5 |
| S/C TX POWER (16 WATTS) dBw | – | 12 dBw | – | 12 dBw | – | 9 dBw |
| EIRP (DOWN) IN 1 dB LOSS | – | 50.5 | – | 50.5 | – | 50.5 |
| GROUND TERMINAL EIRP (500W 8FT) | 81 dBw | – | 81 dBw | – | 81 dBw | – |
| MAX ATMOSPHERIC LOSS (DIY) | 8.8 | 6.7 | 5.2 | 5.2 | 3.5 | 3.1 |
| SPACE LOSS | 214.3 | 211.0 | 214.3 | 211.0 | 214.3 | 211.0 |
| MAX LOCATION LOSS (DIY) IN dB | 2.0 | 1.0 | 2.0 | 1.0 | 2.0 | 1.0 |
| S/C AND TERMINAL G/T* | +8.4 | +23 dB | +8.4 | +23.0 | +8.0 | +23.0 |
| BOLTZMANS CONSTANT | 228.6 | 228.6 | 228.6 | 228.6 | 228.6 | 228.6 |
| C/No SPACECRAFT | 92.9 | – | 96.5 | – | 98.2 | – |
| C/No TERMINAL | – | 83.4 | – | 84.9 | – | 87.0 |
| S/C BANDWIDTH (180 MHz) | 82.6 | | 82.6 | | 82.6 | |
| S/N SPACECRAFT | 10.3 | | 13.9 | | 15.6 | |
| DEGRADATION BY UPLINK NOISE** | | 0.8 | | 0.4 | | 0.4 |
| Eb/No | | 6.0 | | 6.0 | | 6.0 |
| DATA RATE (dB) | | 76.6 | | 78.5 | | 80.5 |
| Mb/s | | 45.7 | | 70.8 | | 114.8 |
| | | ~30 (TI) | | ~(44 TI) | | (74 TI) |

*INCLUDES 1 dB MICROWAVE LOSSES

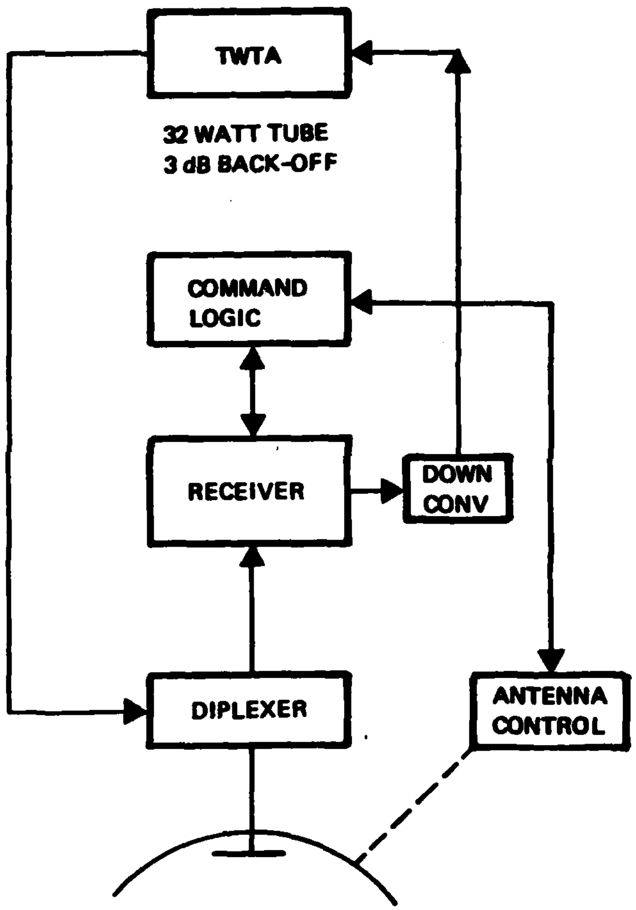
** $1 + \frac{C/N_o\ TERMINAL}{C/N_o\ S/C} + \frac{1}{S/N\ SC}$ = COULD BE REDUCED BY INCREASED UPLINK POWER.

The simplified proposed trnasponder configuration is shown in Figure 5-42 together with a rough estimate of weight and power requirements. A conventional wideband single-channel frequency translation transponder is assumed to be using a 32-Watt TWTA backed off for 16 Watts output to reduce the level of intermodulation products if Frequency Division Multiple Access (FDMA) is used. However, this will not be necessary with Time Division Multiple Access (TDMA) and may not be needed with FDMA if no analog voice is handled.

Weight and power are well within required parameters of a piggy-back transponder configuration, particularly if advantage is taken of the multi-mode TWTA technology previously described in Subsection 5.5.2.3. In this case the TWTA would be operated in a lower power mode (i.e., 16, 8, or 4 Watts) during the smmer months when most stations would be in a fine-weather environment, thus reducing the load on the host vehicle.

The link budgets given in Table 5-24 are based on use of an 8-ft diameter antenna at the terminal and 500-Watt maximum power. In a benign environment the uplink performance is not very critical (except possibly in a TDMA mode) and could be 250 Watts or lower. However, the BAL and ERH stations would impose very modest SATCOM requirements, permitting use of a smaller antenna in the 2 to 4-ft diameter range to gain significant mobility advantages.

5.5.2.6 Connectivity Outside Turkey Region. Connectivity outside the Turkey region is required from Elmadag to Dirmansens (FRG), Mt. Vergine (Italy), and the Washington, D.C. area. There are two sets of potential solutions depending on whether the SATCOM transponder is on the Atlantic Ocean DSCS III or on the Indian Ocean spacecraft.




| | WEIGHT (LBS) | AVERAGE POWER (WATTS) |
|---|---|---|
| ANTENNA SUBSYSTEM | 12 | - |
| RECEIVER | 6 | 18 |
| DOWN CONVERTER | 2 | 6 |
| TWTA | 8 | 100 |
| COMMAND LOGIC | 2 | 3 |
| OVERHEAD | 12 | 20 |
| | 44 | 147 |

Figure 5-42. Simplified Transponder

1. Connectivity Options with EHF Transponder on Atlantic Satellite.

Traffic out of Turkey may be accomplished by any of the following alternatives:

a. The EHF terminal collocated with a currently planned SHF DSCS terminal at Elmadag (or Mt. Pateris) using Indian Ocean satellite to the Landstuhl gateway terminals, which in turn can relay Washington traffic over the Atlantic DSCS spacecraft. Traffic to Primasens would be over the Landstuhl-Donnersberg-Pirmasens microwave circuits, and traffic to Mt. Vergine could use a Landstuhl-Lago di Patria link (with a short microwave tail to Mt. Vergine) over the Atlantic spacecraft.

b. An EHF terminal collocated with the Landstuhl gateway SHF terminals. This would require an additional satellite antenna (or antenna beam) directed at the Landstuhl complex, which would relay to Primasens, Mt. Vergine, and Washington D.C. as in Alternative 1.a. above.

c. A regional channel and a separate out-of-region channel in the EHF satellite transponder that would permit cross strapping with a DSCS III SHF channel in the spacecraft, thus providing direct EHF/SHF conversion and eliminating at least one large SHF terminal in Turkey.

2. Connectivity Options with EHF Transponder on Indian Ocean Satellite.

The connectivity options with an Indian Ocean satellite EHF transponder are basically identical to those of the Atlantic satellite EHF transponder, although the latter also offers the further option of using an EHF terminal in the Washington D.C. area. However, because Washington is subject to a worse rain environment and also because the angle of elevation is significantly worse and thus would require installation of another antenna beam, use of the Atlantic satellite does not appear attractive.

3. Optimum Out-of-Region Connectivity Plan.

Each of the foregoing alternatives offers advantages as well as disadvantages, but because Alternatives 1.b. and 1.c. would require additional spacecraft modification it would appear that Alternative 1.a. is the most attractive for an initial operating capability and most ikely for the ultimate system if only because it offers more operational flexibility. It should be noted that the same system performance can be obtained using either the Indian Ocean or the Atlantic spacecraft as a host vehicle, so that an EHF transponder or both satellites would furnish 100-percent redundancy and would provide alternate paths around the worlds in opposite directions to CONUS if required.

The one situation wherein Alternative 1.b. may be more attractive is the case in which a transponder (or multiple transponders) is used in conjunction with a 6-beam MBA on the Atlantic DSCS III to replace the long-haul troposcatter stations of the European DCS, as discussed in Subsection 5.5.2.4. In this instance separate coverage of Turkey is provided by transponder and a 2-beam MBA antenna subsystem on an Indian Ocean DSCS III. Figure 5-43 shows an optimum 6-beam system for the remainder of the European coverage extending from Greece to Iceland without gaps.

5.5.2.7 Conclusions. It has been shown that an EHF SATCOM system using a simple transponder on either the Atlantic or Indian Ocean DSCS III is feasible and could provide a 46-Mbps capability with 99-percent availability for the long-haul circuits in Turkey, which currently are served by large troposcatter stations. This capability is significantly (11 dB) greater than estimated requirements and may be used to support other services such as wideband circuits and replacement of certain other (shorter) troposcatter links. Alternatively, 99.95-percent availability in bad weather could be achieved and/or smaller antennas used at most of the terminals. Although a preponderance of the necessary technology is already under active development, some development of the dual-beam antenna for optimum coverage from the Indian Ocean Satellite may be required.

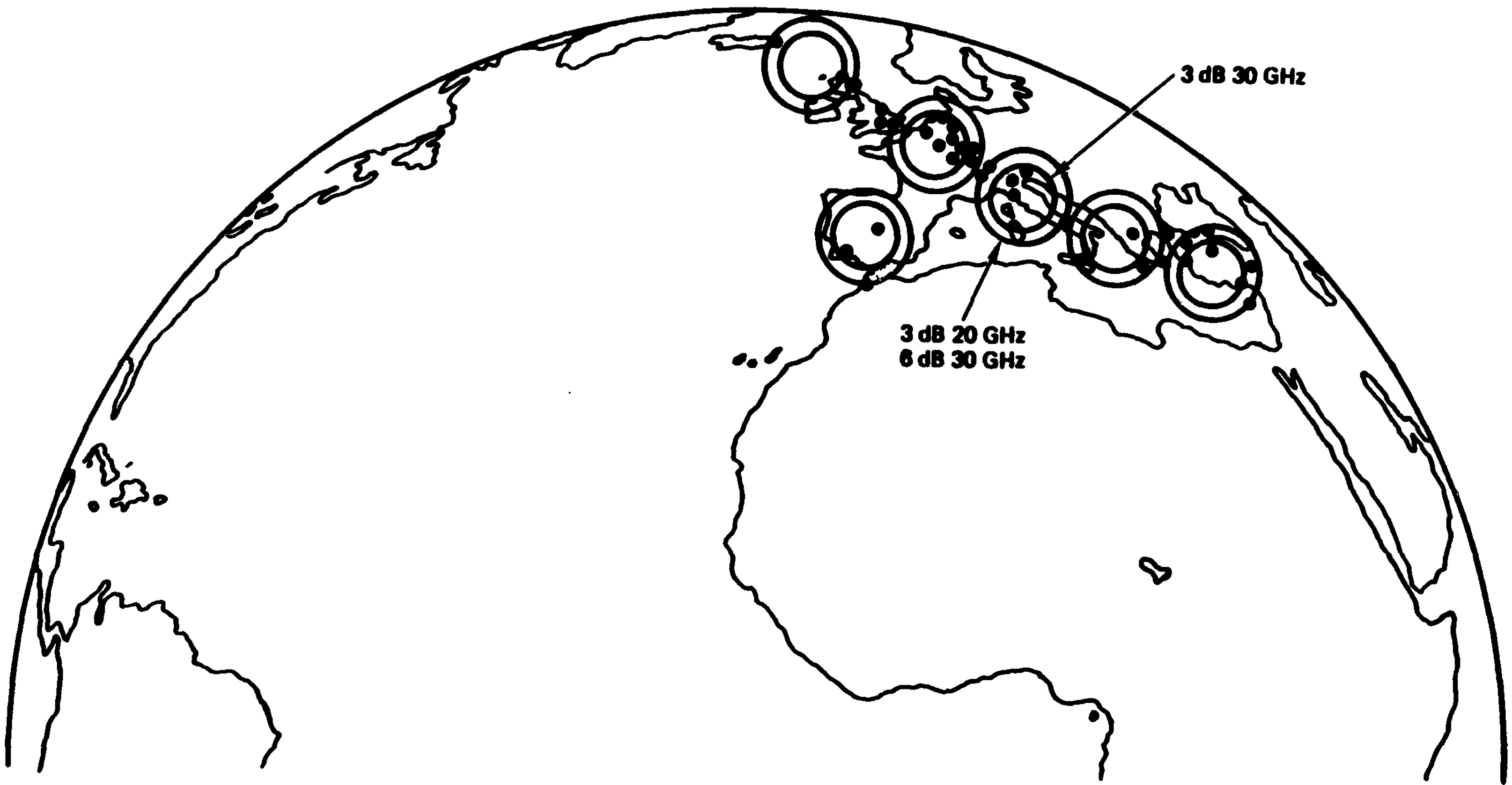



Figure 5-43. Optimum 6-Beam Coverage for Europe from Greece to Iceland

### 5.5.3 Alternative System Design T-2

Due to the particular geographic environment of Turkey which is characterized by large distances between a few number of nodes and separated by sparsely populated mountain regions, the troposcatter system and the EHF satellite appear to be the only two attractive candidates for satisfying communications requirements.

The current proposed upgrade Phase I and II configuration plan is to digitize a few long and important troposcatter links and microwave line-of-sight relay links. One logical alternative transmission system for Turkey is to digitize all remaining troposcatter and microwave links such that by the year 2000 all DCS links in Turkey will be digital. Because of the trend of digitization of DCS, it is therefore assumed that the baseline DCS II system in Turkey will be a completely digitized one consisting of troposcatter and microwave line-of-sight systems. Therefore another feasible alternative transmission is proposed and investigated. The alternative system considered is an airborne relay system.

5.5.3.1 Choice of Relay Platform. Three different airborne platforms have been investigated, and the results are documented in Appendix A to this report. Among the three, tethered balloon and manned and/or unmanned aircraft are currently available for such application. The third one is a high altitude powered platform (HAPP) which is currently being developed for some other purpose.

The maximum altitude of a tethered balloon is about 15,000 ft. or 4.5 km. It appears that further increasing the operating height of a tethered balloon is severely limited due to strength and weight of the tether cable. Aircraft are currently used for communications relay platforms for various purposes. Endurance, initial and operation costs, and logistics are major restraining factors. However, the L-450F aircraft produced by the E-System Company has been identified as a feasible candidate which can orbit at an altitude of 45,000 to 55,000 ft. or 13.7 to 16.8 km for 24 hours without refueling. The aircraft is of the right size for providing the right payload capacity, 1100 lb, and 26 $ft^3$ for relaying. It can be operated as either a manned aircraft or an unmanned aircraft (remotely piloted vehicle). The high altitude powered platform (HAPP) currently being developed for other purposes is also a potential candidate whose operating altitude is 70,000 ft. or 21.3 km. A HAPP could provide a payload capacity more than needed, with a planned endurance of one year.

Apparently HAPP is the best choice. An airborne relay transmission alternative using HAPP is considered, and the system is described in subsection 5.5.3.4. Nevertheless, due to the uncertainty of the HAPP development schedule, an airborne relay system employing L-450F aircraft has been proposed in the following subsection 5.5.3.3.

5.5.3.3 Aircraft Relay System. Turkey is very nearly a rectangular shaped country with a land area of about 767,000 square km. Its east-to-west distance is approximately three times longer than its north-to-south distance. The higher altitude of the airborne relay platform is, the longer the horizontal range of line-of-sight coverage. Therefore it is of advantage to use the high altitude platform.

Two aircraft can cover the communications nodes in Turkey, and the area of coverage of each aircraft is shown in Figure 5-44. Since the system design and performance characteristics of an airborne relay system are already described in Section 5.4.2.2 through 5.4.2.4; they will not be repeated here. The frequencies for uplink and downlink are chosen as 7 and 8 GHz, respectively, for the same reason as described in Section 5.4.2.4. The major parameters of system design are also applicable for each aircraft. Since the required total band width is only about 24 MHz instead of 160 MHz as required in Germany there is an extra margin of 8.2 dB, It should be noted that although two aircraft are within line-of-sight range, the relay between these aircraft are through a ground station located in Elmadag. This is because both aircraft are orbiting at their stations independently and continuously. High gain antennas with pencil beams cnanot be used for inter-aircraft relay. Low gain antennas with pancake-like-radiation patterns may be used but these antennas are subject to jamming. Elmadag is chosen as the ground relay station between these two aircraft because its location and importance in the system.

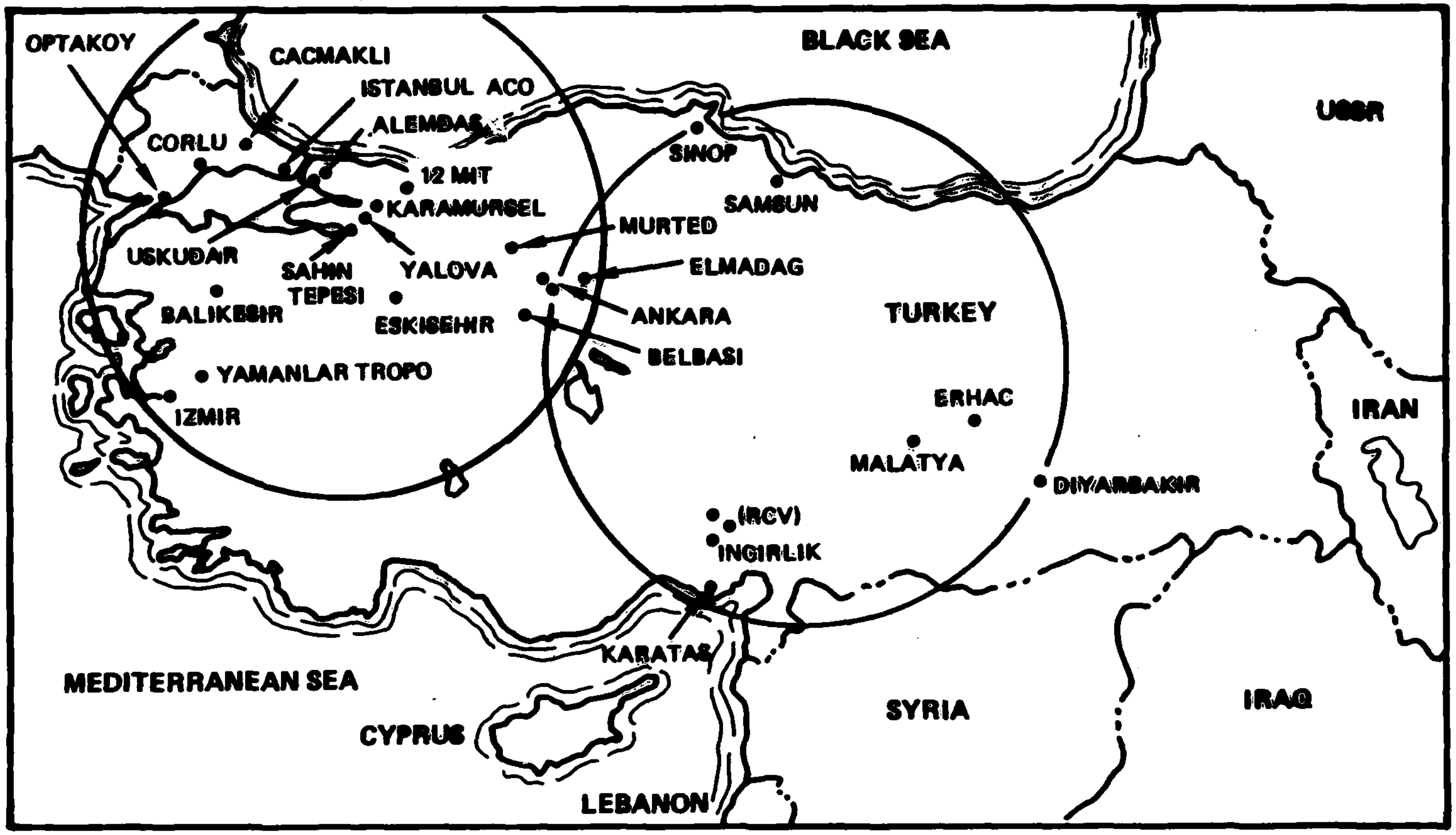



Figure 5-44. Airborne Relay System for Turkey

5.5.3.4 High Altitude Powered Platform Relay System. Since the assumed frequency of 7 and 8 GHz with a bandwidth of 25 MHz may be hard to allocate, it is considered increasing the frequency to the 30-40 GHz range where they are presently unassigned. In so doing the floating airborne platforms have to be modified so that the minimum receiving elevation angle has to be increased to reduce the atmospheric attentuation.

Atmospheric components such as humidity, clouds and rain can degrade the performance of the earth to the floating platform communication system. This degradation is particularly significant at higher frequencies. Detailed discussion on atmospheric attentuation effect is given in Section A.6 Millimeter Wave Technology, and Section A.7 EHF Satellite Communications, of Appendix A to this report.

In general the cosecant law is followed by the attentuation data. This dependence on the cosecant of the elevation angle is to be expected because the attenuation is caused by humidity, clouds and light rain, which all can be reasonably expected to be horizontally stratified. In addition, the top of clouds and rain are usually limited to a relatively low altitude.

The High Altitude Powered Platform (HAPP) is an unmanned vehicle which could be an airship or an airplane. It would keep stations at an altitude of 70,000 ft., above a fixed point on the ground as described in Section A.16 High Altitude Powered Platform Characteristics in Appendix A to this report.

Assume the same approaches are used in the HAPP relay communication link as in the aircraft relay communication link, except that they are operated at different frequencies and at different altitudes. Using a transmitter power of 200 watts in both the ground and floating platform, the link budget is prepared as shown in Table 5-25. The 12 MHz QPSK transmission for the 16 T1 data rate will have a system margin of 9.8 dB.

Table 5-25. HAPP - Ground Link Budget at 35 GHz

| | Downlink | Uplink | Note |
|---|---|---|---|
| Frequency GHz | 35.0 | 36.0 | Assumed |
| Transmiter Power dBw | 23.0 | 23.0 | 200 watts |
| Transmitter Circuit Loss dB | 2.0 | 2.0 | |
| Transmitter Antenna Gain dB | 3.0 | 3.0 | Hemispheric |
| Space Loss dB | 174.5 | 174.5 | 350 km range |
| Receiver Antenna Gain dB | 44.3 | 44.5 | 2-foot 55% Efficiency |
| Atmospheric Loss dB | 2.0 | 2.0 | Assumed |
| Receiver Front End Circuit Loss dB | 2.0 | 2.0 | |
| Received Input Power dB | -109.0 | -109.0 | |
| Receiver System Noise Temperature °K | 500.0° | 500.0° | Assumed |
| Noise Spectral Density dB $N_0$ dB | -195.6 | -195.6 | |
| Received Power to Noise Spectral Density Ratio $C/N_0$ dB | 99.6 | 99.6 | |
| $E_b/N_0$ Required for QPSK dB | 10.6 | 10.6 | BER = $10^{-6}$ |
| Bandwidth 12 MHz dB/Hz | 70.8 | 70.8 | 24 Mbps data rate |
| System Margin | 9.8 | 9.8 | |

## 6.0 PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

The Phase 1A effort of DCS III Transmission Alternatives Program has been documented in this final report and its three associated appendices. Based on results obtained so far, some preliminary conclusions can be drawn which are presented in Section 6.1. During the course of this work some areas needing further research and development have been identified, and recommendations on transmission media and systems are discussed in Section 6.2. However, it should be noted that both conclusions and recommendations presented and discussed in these sections are of a preliminary nature at best. They need further definition and substantiation to be accomplished during completion of this program.

### 6.1 PRELIMINARY CONCLUSIONS

Regarding the transmission media, it is concluded that the final results are what had been expected at the onset of this study and that no unexpected promising media was discovered.

One new transmission media which will be used extensively is the rapdily developing fiber optics. Optical transmission over a dielectric fiber has reached a fully commercial stage with carrier wavelengths in the 800-900 nm region. Second generation optical communications systems will operate in the carrier wavelength in the 1200-1500 nm region where fibers have more attractive loss and dispersion characteristics. Research efforts continue at a high level worldwide and will lead to rapid evolution of optical communications systems. Presently almost all research and development work done in this field is initiated and sponsored by commercial enterprises. However, some work in tactical and long haul communications systems study have been sponsored by the U.S. Army, and the U.S. Navy also is working on submarine fiber optics research.

Another transmission medium which has experienced rapid advancement is the millimeter wave technology. There are currently very heavily research and development activities on millimeter waves, sponsored either by government agencies or by private enterprise; emphasis has been placed on either components or devices. Much of the new technology in millimeter waves relates to the use of frequencies from 10 to 36 GHz where the less atmospheric attenuation window exists. The advantages of such frequencies are that the available bandwidths are wide and the radio congestion of lower frequencies is avoided. However, there is one major disadvantage. The signals are heavily attenuated by rain and by the atmosphere. Very heavy rain is often isolated and is limited in area, which raises the possibility of automatically switching transmission to alternate paths when storms occur. The high attenuation means use of short hops with many repeaters. The repeater, therefore, must be of low cost and high reliability. It must require little or no manual attention or maintenance.

Another transmission medium related to millimeter wave is the developing EHF satellites. The proliferation of UHF satellite networks throughout the world is extensive and mutual interference between satellite and terrestrial service is a serious problem. The 7/8 GHz band is allocated for fixed satellites and is also shared with terrestrial systems. Satellites operating in this band require entensive frequency management on a global basis and they are becoming increasingly more difficult to coordinate. There are some higher frequency satellite system experimental programs. EHF satellites operating in 20/30/40 GHz bands could provide improved long haul communications for DCS of the 1990 time frame. The advantages of the EHF band are irresistible. These include:

- Extra (wider) bandwidth
- Higher gain and physical small antenna
- Less effective jamming threat
- Multiple spot beam antenna
- Low cost earth stations.

EHF satellite capability has been already planned for MILSATCOM, the proposed EHF satellite system for Turkey, if adopted, should be integrated with other MILSATCOM programs.

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Strictly speaking, packet radio is not a transmission medium but rather a means of efficient utilization of a medium. Currently interest is either for tactical use or for a highly survivable and emergency communications requirement. Use of packet radio for a long haul, wideband data and voice need has not really been addressed yet. It appears that the utilization of the packet radio technique has to be addressed in a realistic scenario or a hypothetical network. The proposed millimeter wave LOS system in Oahu Island is a suitable example for investigation and assessment of the advantages of the packet radio system. That system as shown in Figure 5-14 is a multiple loop network; packet radio switching could be used advantageously. For this investigation, a few more branches may be added to close some open loops; these branches are Kaena Point to Schofield or Wahiawa, Wahiawa to Camp Smith, Camp Smith to Ft. Shafter, and Camp Smith to BEllows. Packet radio can also be applied to common channel satellite systems, for example the EHF satellite system proposed for Turkey and the airborne relay system proposed for Turkey and Germany can be used as realistic cases to examine the utility of packet radio technique.

## 6.2 PRELIMINARY RECOMMENDATIONS

Preliminary research and development recommendations identified at the conclusion of the Phase IA study are:

- Atmospheric effects on millimeter wave propagation
- Millimeter wave LOS communications system development
- Packet radio application study
- Monitoring airborne relay platform development
- Platform antenna array and adaptive control electronics development
- Submarine cable employing optical fibers.

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